G.E.C. Journal

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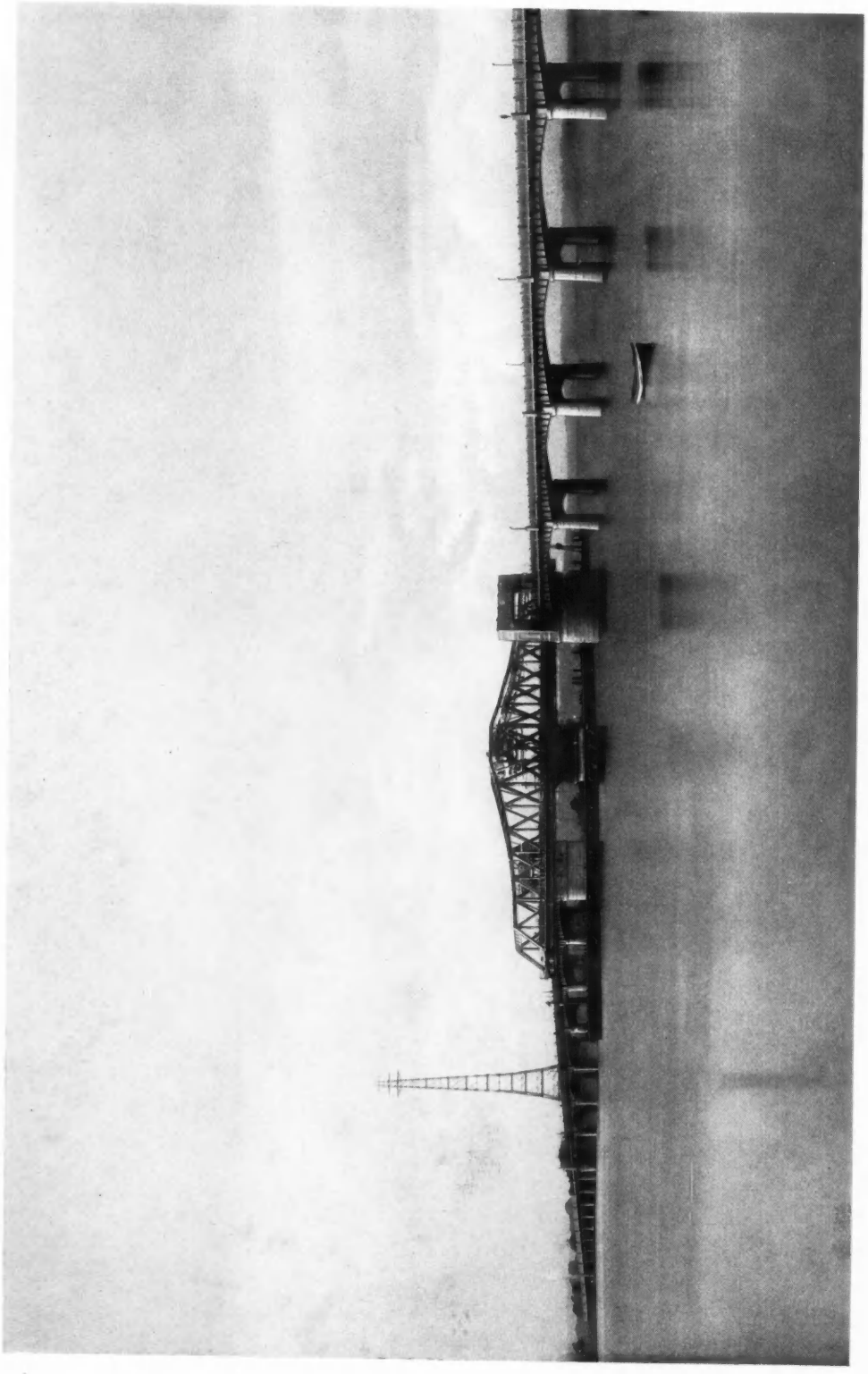


KINCARDINE-ON-FORTH BRIDGE.

A description of the electrical control of the swing span starts on the next page.

G.E.C. Journal

VOL. VII. NOVEMBER, 1936. No. 4.

The Electrical Control of the Swing Span of Kincardine-on-Forth Bridge.

By S. A. G. EMMS, B Sc., Switchgear Dept., G.E.C. Witton Engineering Works

and D. C. ROGERSON, B.Sc., Assistant Editor of the G.E.C. Journal.

THE opening to road traffic of the Kincardine-on-Forth bridge on the 29th October by the Convenors of the counties of Fife, Stirling and Clackmannan marks a further stage in the development of road communication across the Firth of Forth. Prior to its completion the only means of crossing the Forth for road vehicles was the ferry at Queensferry alongside the railway bridge, or the bridge across the river at Stirling 25 miles west.

Stirling bridge has thus been, in effect, the bottleneck for all Central Scotland traffic crossing the Forth and the increasing use made of this bridge by road vehicles in recent years is reflected in the traffic census returns which show a rise from 150 vehicles per hour in 1922 to 400 per hour in 1935.

The new bridge at Kincardine is located as far down the river as is practicable. Immediately east of Kincardine the river broadens out into an estuary and, thereafter, the only practicable locations for crossings are fully 10 miles downstream where the cost

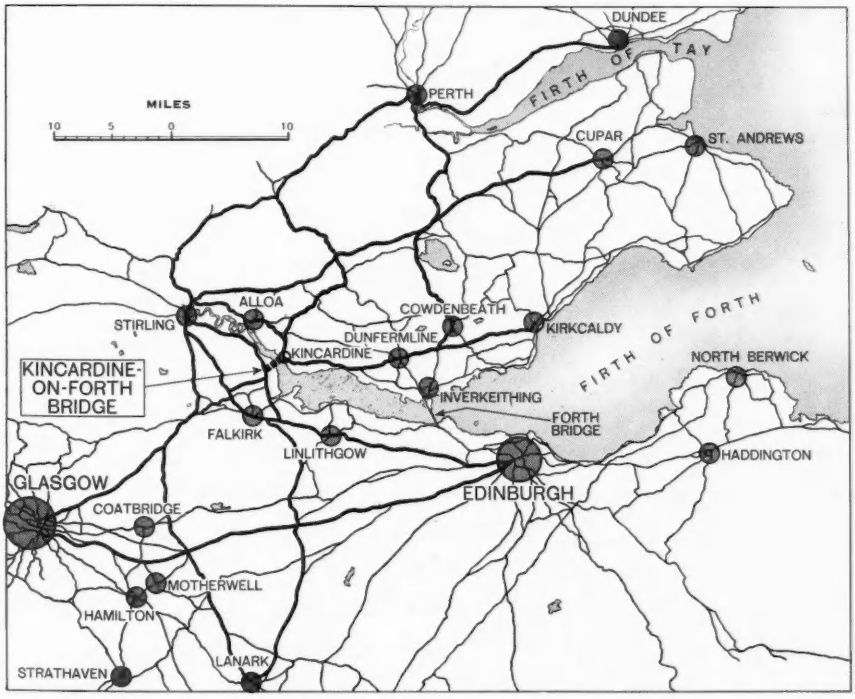


Fig. 1.—Map of district, showing location of the new Kincardine-on-Forth Bridge and its importance as a connecting link between central Scotland and the North East.

By courtesy of Sir Alexander Gibb and Partners.

of a structure would be 10 to 15 times that of the bridge at Kincardine.

As will be seen from the map of the district, fig. 1, the new bridge is 15 miles west of Queensferry and 9 miles south east of Stirling. As a result, for a large proportion of Central Scotland traffic, the bridge not only cuts off about 20 miles of the detour which was necessary *via* Stirling bridge, but also enables delay to be avoided at Stirling due to traffic congestion.

Typical examples of the mileage savings which are effected by the new bridge are as follows :—

Route.	Distance *via* Stirling Bridge	Distance *via* Kincardine Bridge	Saving in Mileage	Percentage Saving
Edinburgh to Dunfermline	58	38	20	35
Edinburgh to Perth ..	70	62	8	11
Falkirk to Dunfermline ..	32	17	15	47
Glasgow to Dunfermline ..	47	37	10	21
Lanark to Alloa	41	36	5	12
Linlithgow to Dunfermline	38	20	18	47

It will be seen that the new bridge will benefit Edinburgh and Glasgow traffic bound for Fife and the north as well as north-south traffic. It gives in addition an attractive alternative route to Perth.

The scheme for the Kincardine-on-Forth bridge was initiated by the three counties of Fife, Stirling and Clackmannan. Financial contributions were subscribed by the burghs of Falkirk and Dunfermline, while a grant was also made by the Ministry of Transport to the amount of 75 per cent of the total cost of the structure which, including approach roads, land and other expenses, amounted to about £350,000.

The bridge was designed by Sir Alexander Gibb & Partners of London, and the contractors for its construction were the Cleveland Bridge & Engineering Co., Ltd., of Darlington. The total length of the bridge is just over half a mile. One of its chief points of interest, and one with which this article is mainly concerned, is the swing span in the centre of the bridge. This span rotates on a central pier, weighs 1,600 tons and has a length of 364ft., providing two clear openings for shipping, each 150ft. wide. Starting from the south bank, the swing span is approached by an embankment and a viaduct 265ft. long, supported on piles driven through about 45ft. of soft mud into gravel. The remainder of the bridge on this side consists of nine 50ft. reinforced concrete spans and seven 100ft. steel spans constructed as a system of cantilevers with suspended spans. From the northern bank the swing span is approached by a similar embankment and three 62ft. 6ins. continuous steel spans over the L. & N.E. Railway, followed by seven 100ft. steel spans. A roadway, 30ft. wide, is

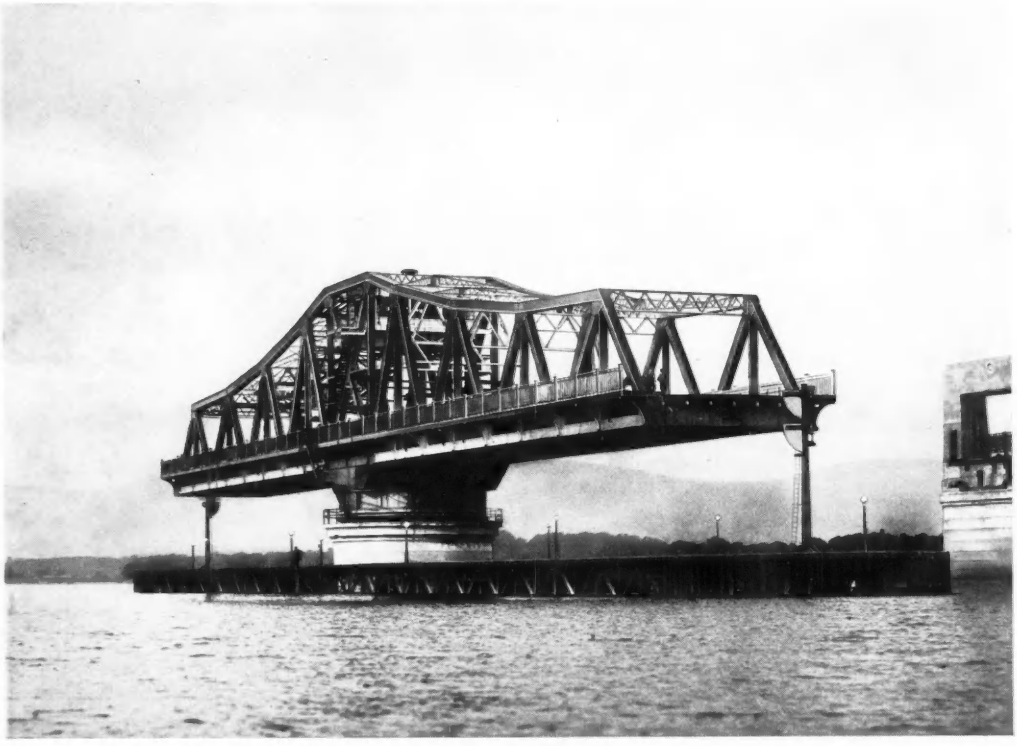
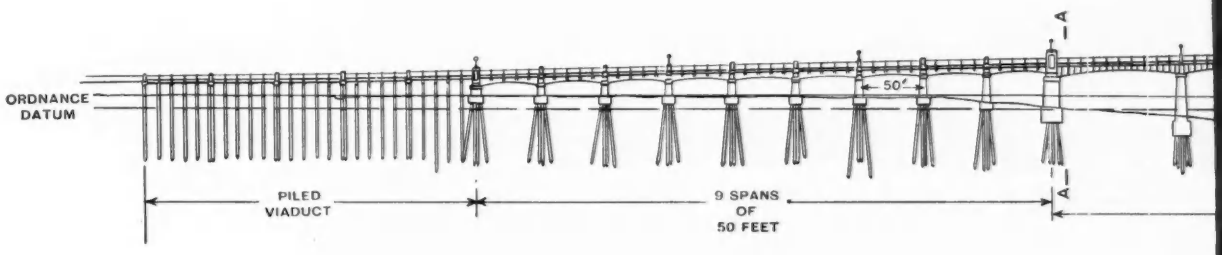
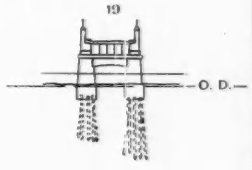
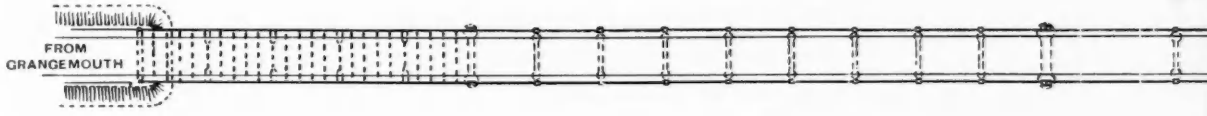


Fig. 2.—The swing span of Kincardine-on-Forth Bridge in the "open to river traffic" position. This view shows the semaphores used to signal to vessels passing through the bridge.


A
ORDNANCE DATUM
50'
PILED VIADUCT
9 SPANS OF 50 FEET
A

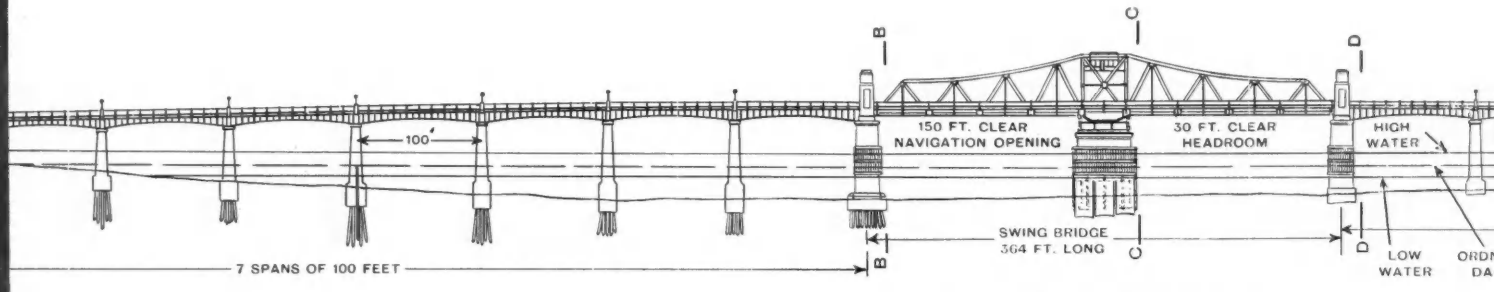

19
O. D.

SECTION A-A

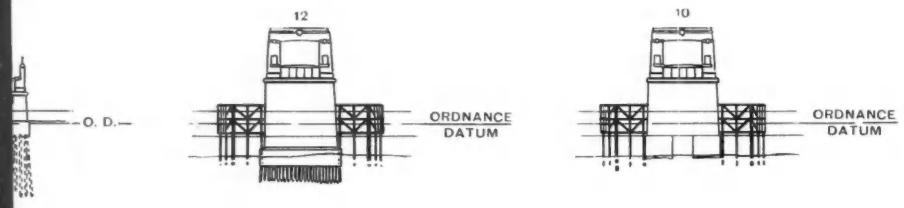

FROM GRANGEMOUTH

10 0
100
200
300
FEET

Kincardine-on-Forth Bridge.



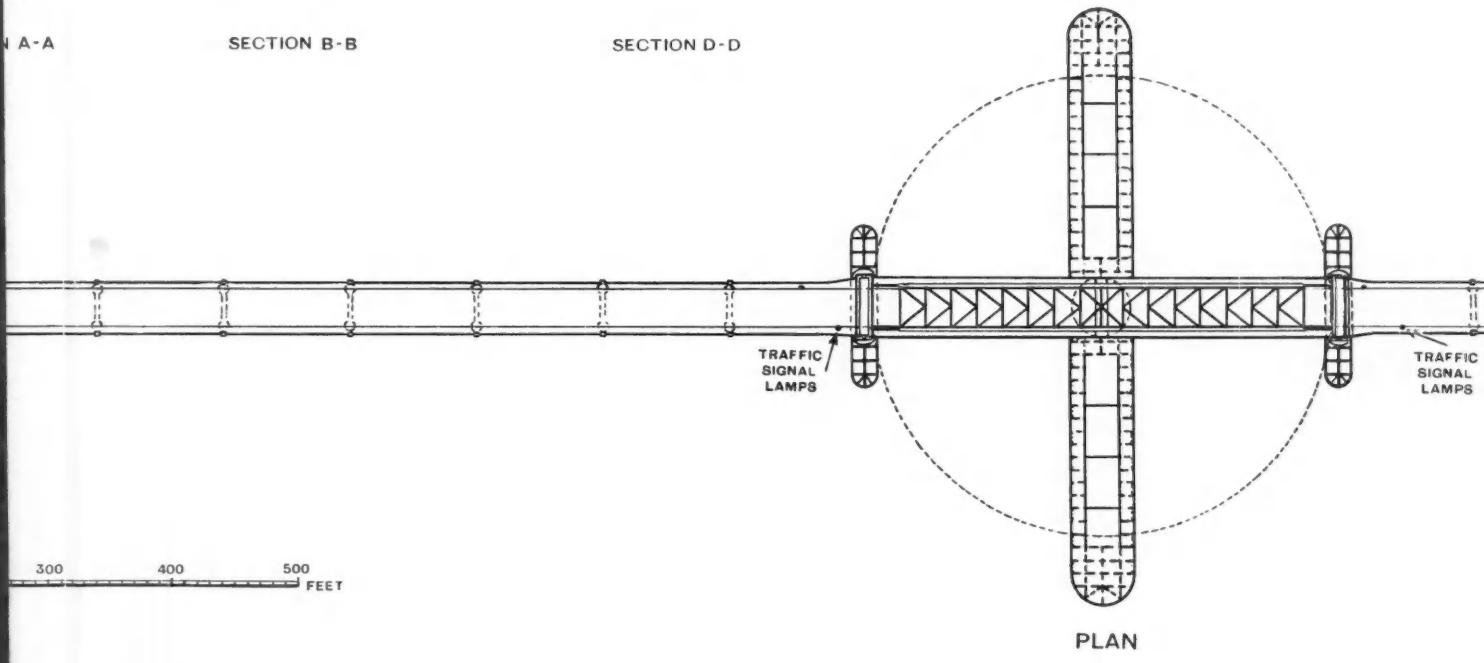
ELEVATION LOOKING WEST



A-A

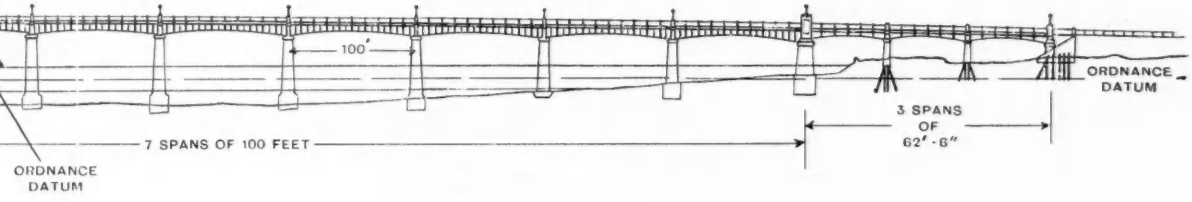
SECTION B-B

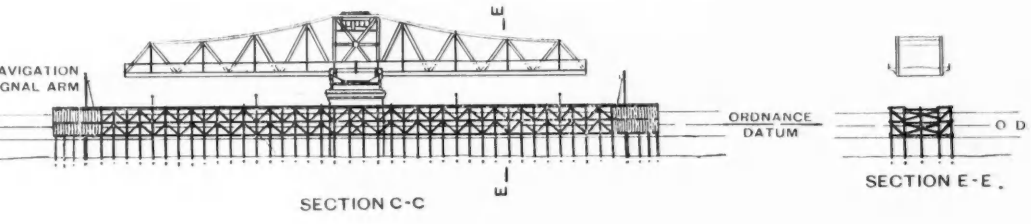
SECTION D-D

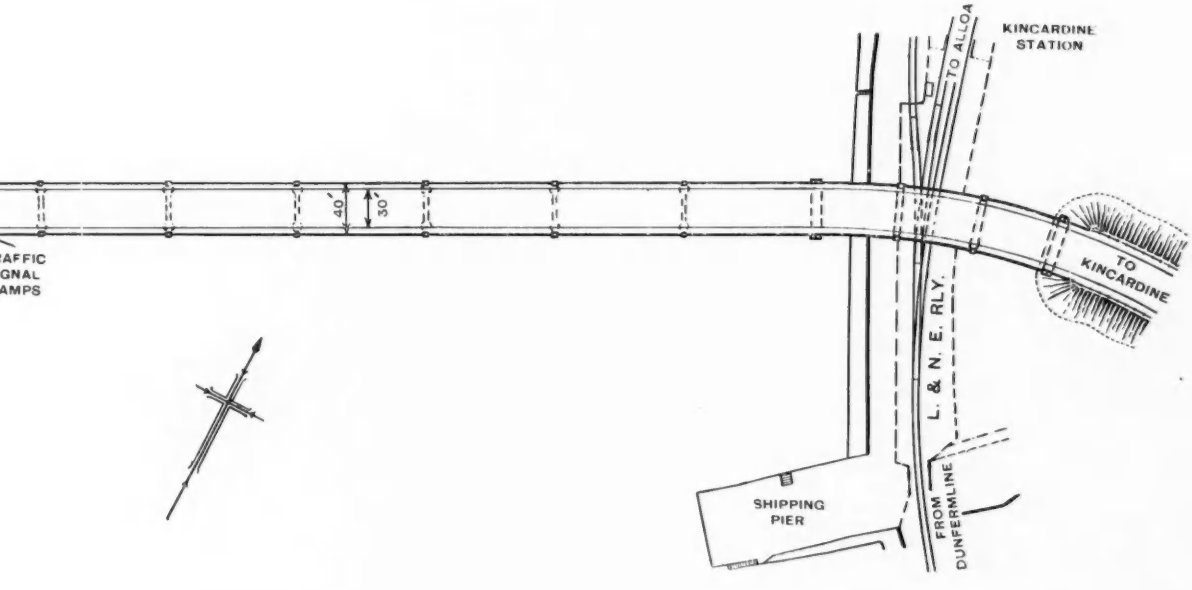


PLAN

Fig. 3.—General plan and elevation.







By courtesy of Sir Alexander Gibb and Partners.

constructed over the bridge, with two footpaths each 5ft. wide, supported on a cantilever construction along each side of the main structure. A general view of the bridge is given in the frontispiece, while a plan and elevation are shown in fig. 3.

THE SWING SPAN.

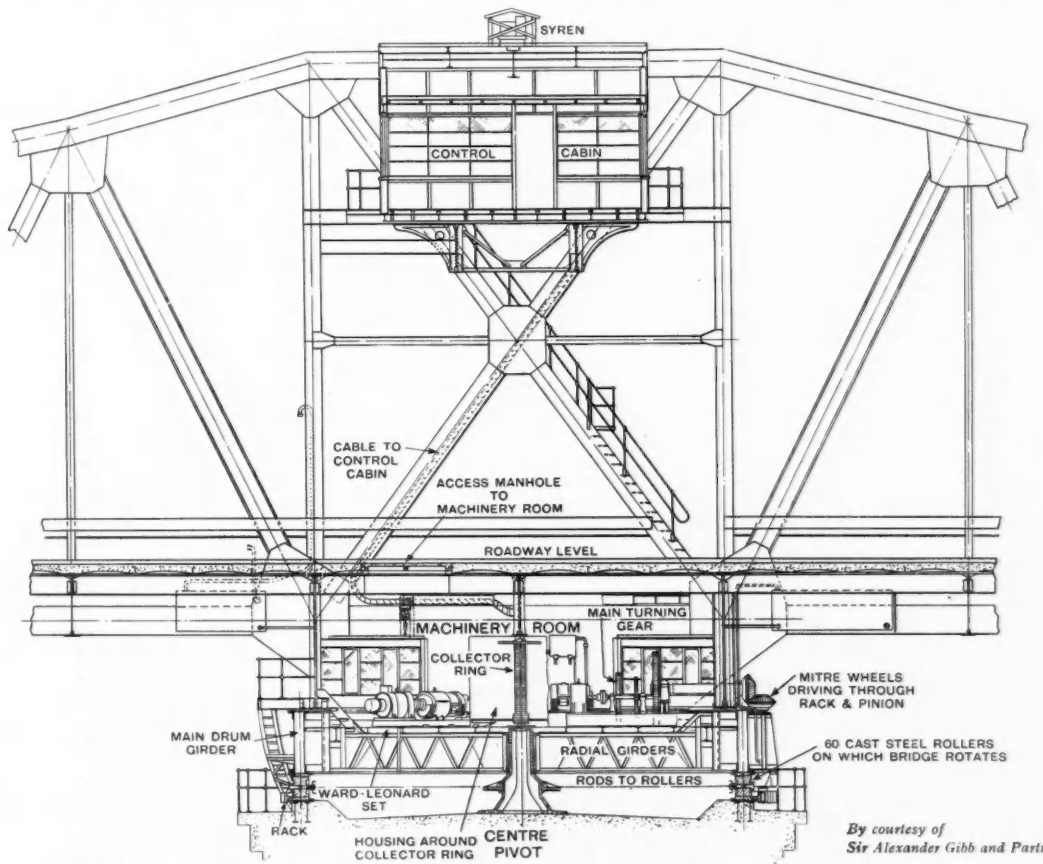
The swing span comprises a double cantilever of open Warren type construction with four panels 40ft. long on each side of the central panel. A system of cross girders and longitudinal stringers carries the roadway, while substantial wind bracing is provided at the top booms. The weight of the structure is taken by two longitudinal and two transverse distributing girders on to a drum girder of 36ft. 9⅜ins. mean diameter, resting on sixty tapered cast steel rollers which travel on an accurately laid steel path constructed on the top of the pier.

It will be seen from figs. 3 and 4 that the swing span rotates about a central pivot and is so designed that rotation of the span can be effected in either a clockwise or anti-clockwise direction. The driving mechanism which, together with main and standby power plant, pumping equipment, etc., is installed in a machinery room situated between the roadway and the drum girder, comprises, briefly, two 50 h.p. electric motors, each driving a pinion which engages with a stationary rack bolted to the fixed portion of the centre pier. The driving mechanism and the sequence of events involved in operating the bridge, are controlled from a control cabin situated 30ft. above the roadway in the centre of the swing span. A sectional drawing of the swing span showing the relative positions of the machinery room and control cabin is given in fig. 4.

In designing the operating and controlling equipment for the span the following considerations had to be taken into account:

(1) The necessity for accurate alignment and levelling on moving the span into the "through-road" position, involving sensitive equipment for controlling the motion of the span, together with means of indicating to the operator when the span is in accurate alignment.
(2) The provision of suitable automatic warning devices to shipping, traffic and pedestrians.
(3) The provision of protective devices, interlocks, and standby equipment in case of failure of the main electricity supply or part of the equipment.

As regards the first of these considerations, the span is accurately aligned by means of special



By courtesy of Sir Alexander Gibb and Partners.

Fig. 4. Sectional elevation of swing span, showing machinery room and control cabin.

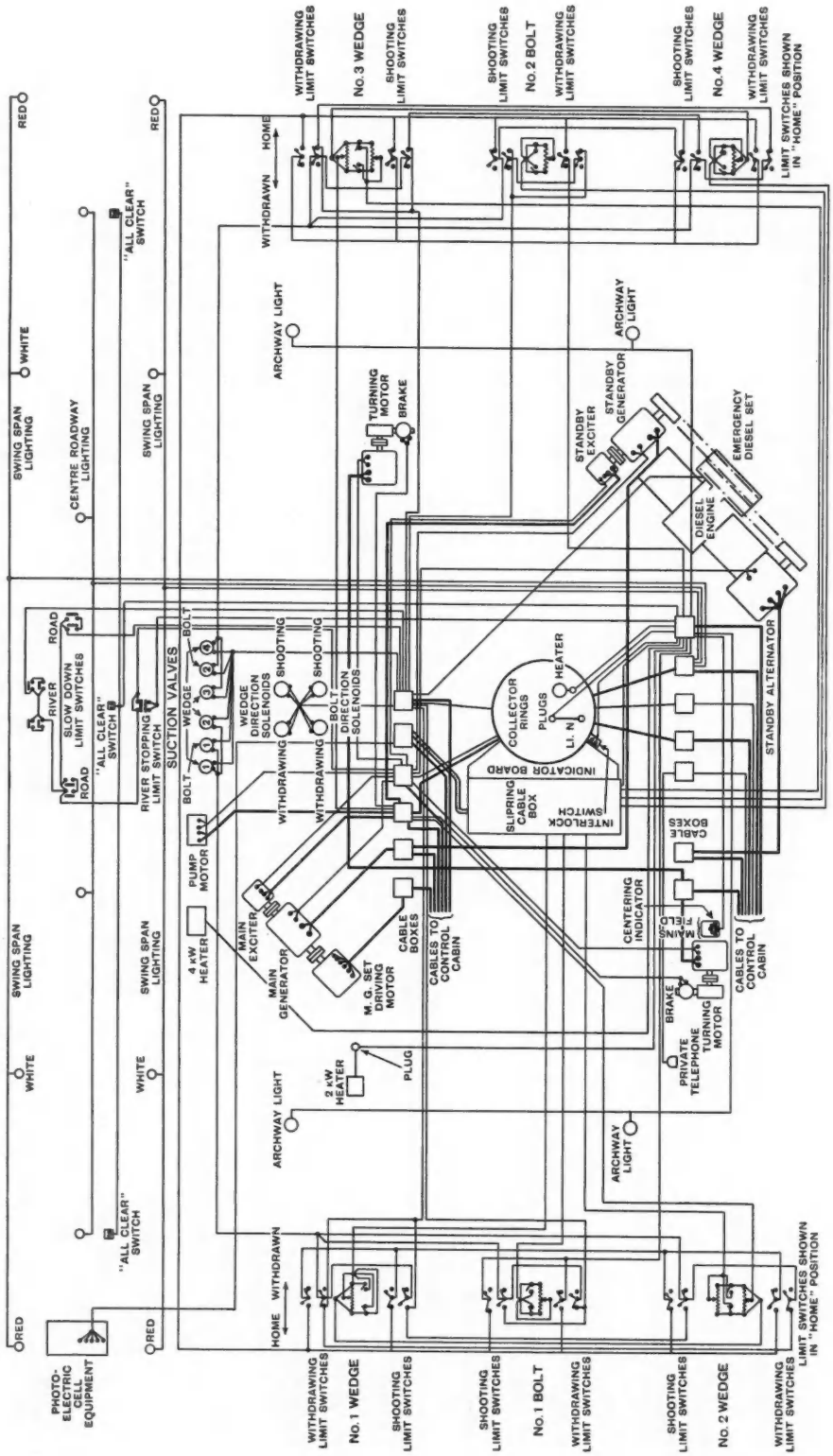


Fig. 5.—General wiring diagram of equipment in machinery room.

photoelectric cell equipment in conjunction with automatic indicating devices. It is believed that this is the first instance in the world of the application of photoelectric cells to bridge control. A target sighting arrangement is also installed as a standby.

When the span is in the "through-road" position, it is locked by hydraulically operated bolts, electrically controlled from the operator's cabin, while hydraulically operated wedges, similarly controlled, ensure that the ends of the span, which deflect to a certain degree in the open position, are levelled with the abutment road surface and adequately supported by the abutments when in the "through-road" position.

The second consideration refers to the warning of shipping and traffic that an operation of the swing span is about to take place or has been completed. The signals for this purpose comprise :—

(*a*) Traffic lights and separate pedestrian lights, mounted at each abutment.
(*b*) Warning bells for traffic.
(*c*) The raising and lowering of a gate at each abutment to cut off all road traffic.
(*d*) A syren, mounted on top of the centre panel of the swing span to warn shipping.
(*e*) Two semaphores at each end of the jetty for signalling to shipping. This jetty protects the span when in the open position for navigation.

These signals are all performed automatically once the sequence of operations involved in moving the swing span has been started by the operator.

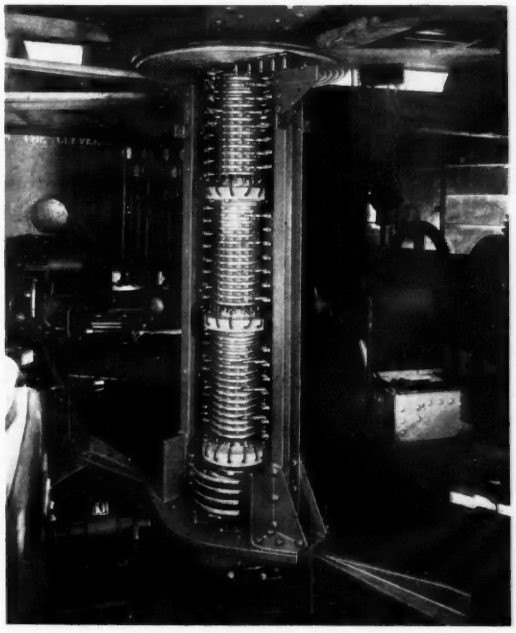


Fig. 6.—Slipring column in machinery room ; view with cover removed.

The third consideration mentioned is concerned with protective devices, interlocks and standby

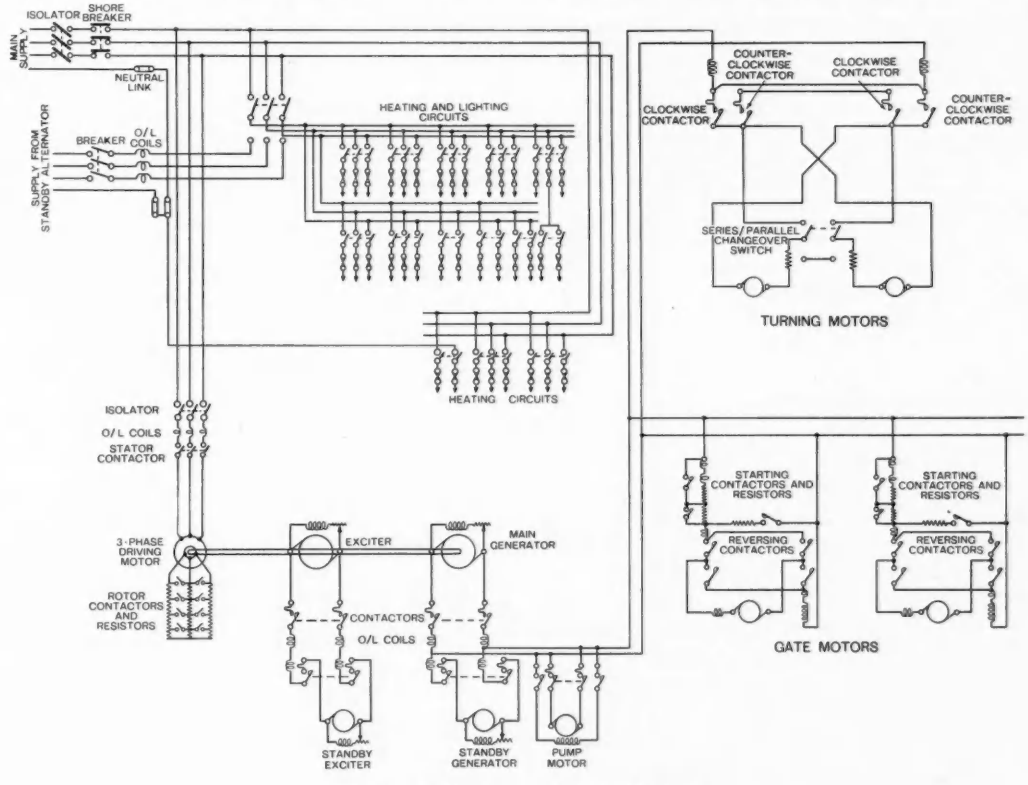


Fig. 7.—Main power circuit diagram.

equipment. These will be described as they occur in the remainder of this article which deals in more detail with the equipment installed and its functions.

It should be mentioned before concluding these introductory remarks that the whole of the control gear installed in the swing span, together with the traffic control, warning devices, etc., and the complete

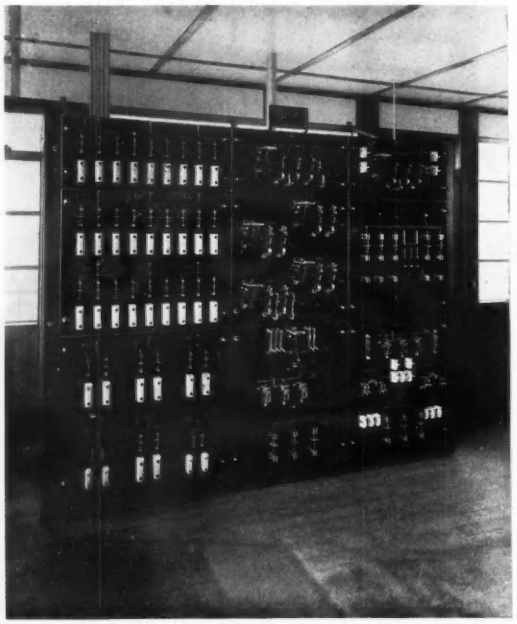


Fig. 8.—Section of main switchboard controlling motor of Ward-Leonard set, lighting, heating and other auxiliary circuits.

lighting installation, was designed and manufactured by The General Electric Co., Ltd., the photoelectric equipment being designed and made by the G.E.C. Witton-Kramer Department.

MACHINERY ROOM.

The electrical power plant employed to operate the swing span is installed in the machinery room. The plant comprises two 50 h.p. motors driving the turning gear of the swing span, an 80 kW Ward-Leonard motor-generator set supplying the driving motors with direct current, an oil-engine driven alternator (25 kW) and D.C. generator (27 kW) acting as a standby in the case of failure of current from the shore, together with electrically driven air compressors for charging the starting bottles of the oil engine. There is also a 25 h.p. motor-driven hydraulic pump supplying oil under pressure for the operation of the bolts locking the swing span in position and the wedges which lift the ends of the span level with the abutments.

It will be appreciated that as the machinery and control rooms move with the swing span and are supplied with power from the shore, and as much of the lighting and signalling apparatus, traffic gates, telephones, etc. is installed on fixed portions of the bridge but controlled from the moving span, means had to be provided for the necessary sliding connections. This is accomplished by bringing the incoming supply and the outgoing control cables to a special collector gear, comprising a slipring column which is situated in the centre of the machinery room. The slipring column is bolted to the fixed pivot, round which the span rotates, while the brush gear rotates with the swing span. A total of 60 rings are mounted on the slipring column (see fig. 6) and the whole is enclosed in a sheet steel casing. Access to this collector gear can be obtained only when the main supply is cut off. The withdrawal of the door bolt on the casing automatically trips the main circuit breaker.

A remote-controlled motor-operated oil circuit breaker, opened and closed from the control cabin is installed on the shore end of the bridge to control the main supply. Thence the power supply is brought to the collector gear *via* a Pirelli-General submarine cable. In the event of failure of this

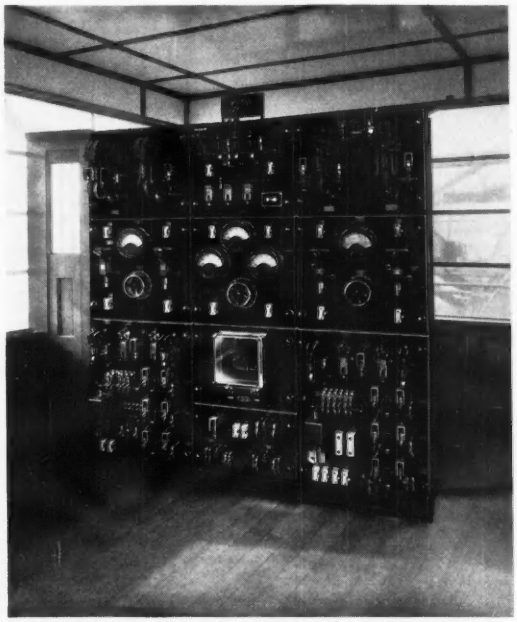


Fig. 9.—Section of switchboard controlling main and standby generators. The accelerating and slow-down relays of the turning motors are also mounted on this board.

supply the swing span may be moved at half speed by connecting the two driving motors in series and supplying them with current from the standby oil-engine driven generator. This engine, which can be operated by remote control from the cabin, also drives an alternator to supply the bridge lighting in such emergency.

The bolts and wedges situated at each end of the span (see fig. 20) are, as has already been stated, operated by double-acting hydraulic cylinders connected to electrically-driven pumps and control valves in the machinery room and

operated from the control cabin. As it is important that the four wedges should be driven and withdrawn simultaneously and also that their positions should be accurately known to the operator, each wedge is coupled through screw gearing to a weather-proof potentiometer regulator acting in conjunction with synchronizing gear which will be described subsequently. The bolts are also synchronized. In emergency the bolts and wedges can be operated by a hand pump situated in the machinery room. Indicators mounted on the steel casing of the slipring gear show the position of the bolts and wedges for the guidance of the person operating the hand pump. A diagram is given in fig. 5 which shows the wiring arrangements in the machinery room and the swing span, while fig. 7 shows the main power circuit.

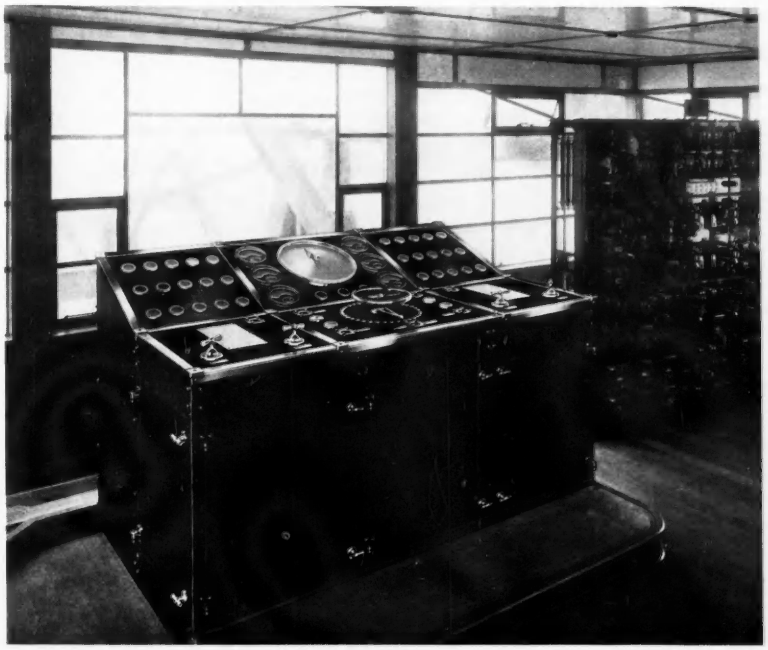


Fig. 11.—Control desk from which the entire operation of the swing span is controlled.

CONTROL CABIN.

The whole of the equipment so far described, including power plant, traffic gates, signalling devices, swing span turning gear, etc., is operated from the control cabin where a main switchboard is installed and an operator's desk from which the switchboard is governed.

The main switchboard is divided into three sections on each of which are mounted various relays, switches and contactors. The first section, fig. 8, controls the motor of the Ward-Leonard set and carries contactors and isolating switches for lighting, heating and other auxiliary circuits. The second section, fig. 9, controls main and standby generators, accelerating and slow-down relays for the turning operations, while the third section, fig. 10, comprises traffic gate and pump motor panels, wedge and bolt synchronizing gear and relay panels in connection with the turning gear.

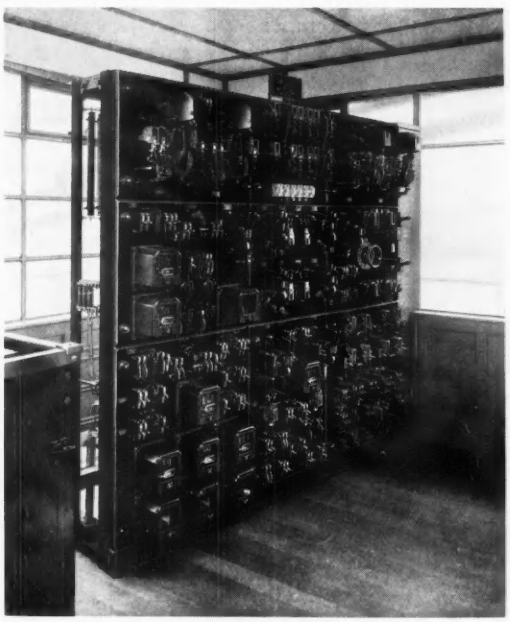


Fig. 10.—Section of switchboard controlling traffic gates, pump motor, wedge and bolt synchronizing gear and relays in connection with turning gear.

The operator's desk, figs. 11 and 12, is the nerve-centre of the installation, the whole of which is controlled at this point. On the desk are mounted the main control handwheel, various master switches and push buttons and a total of 37 indicating lamps. In the centre of the desk, above the control handwheel, is a large position indicating dial, 18ins. in diameter, which shows the operator the position of the swing span at any point in its travel through 90°. It is driven by one of the bridge turning motors through the medium of a pair of "Twyntorq" machines. Flanking each side of this dial are three smaller indicators showing the position of the two bolts and the four wedges. An arrangement drawing of the operator's desk is shown in fig. 13.

It should be noted that the operator's control over the sequence of operations which automatically occur in the course of opening or closing the swing span is exerted solely through the main handwheel on the control desk. When this is moved in either direction an impulse is transmitted to one of the

two pilot motors driving the main drum controller mounted inside the desk (see fig. 12), causing the drum to move and follow the handwheel. The motion of the drum is, however, automatically held up from time to time to await the completion of each operation, and is finally arrested when the drum position corresponds with the handwheel position.

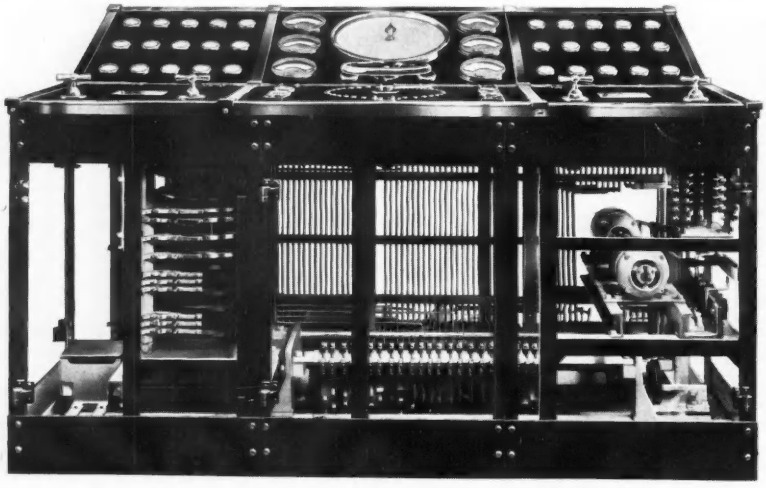


Fig. 12.—Another view of the control desk showing the pilot motors on the right driving the main drum controller.

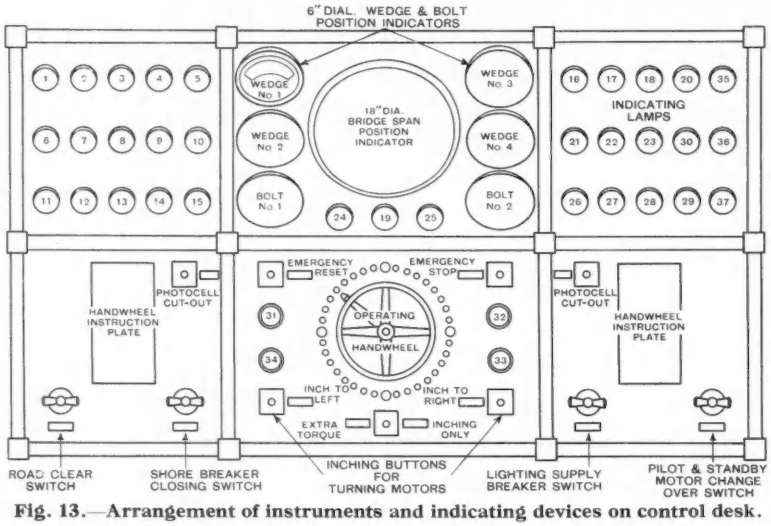


Fig. 13.—Arrangement of instruments and indicating devices on control desk.

KEY TO REFERENCES.

Ref. No.	Indication of Lamp.	Ref. No.	Indication of Lamp.
1	Gates open.	18	No. 3 wedge out of step.
2	Gates closed.	19	Bridge centred (orange glass).
3	No. 1 wedge out of step.	20	Bridge moving.
4	No. 1 wedge drawn.	21	No. 4 wedge home.
5	No. 1 wedge home.	22	No. 4 wedge drawn.
6	Traffic lights (red glass).	23	No. 4 wedge out of step.
7	Traffic lights (green glass).	24	Bridge left centre (red glass).
8	No. 2 wedge out of step.	25	Bridge right centre (green glass).
9	No. 2 wedge drawn.	26	No. 2 bolt home.
10	No. 2 wedge home.	27	No. 2 bolt drawn.
11	Semaphore upper.	28	No. 2 bolt out of step.
12	Semaphore lower.	29	Bridge open.
13	No. 1 bolt out of step.	30	Gate warning lights.
14	No. 1 bolt drawn.	31	Shore breaker open (green glass).
15	No. 1 bolt home.	32	Lighting breaker open (green glass).
16	No. 3 wedge home.	33	Lighting breaker closed (red glass).
17	No. 3 wedge drawn.	34	Shore breaker closed (red glass).

Motion of the handwheel is restricted to any one quadrant, unless the bridge position corresponds with the handwheel position, when it is free to move 90° in either direction. The progress of the sequence of operations is shown by the lighting up of the various indicating lamps, each bearing in illuminated letters the operation to which it refers. The method of control adopted may best be understood by following through the sequence of events (given in the next section of this article) which occur when the swing span is to be opened for river traffic.

Special care has been taken to ensure proper protection of this equipment in the cabin as well as the comfort of the operators who are in charge of the bridge. The total staff consists of three skilled operators and three labourer assistants, each working an eight-hour shift. By this means, the bridge will be manned throughout the twenty-four hours.

The cabin itself measures 28ft. long by 22ft. wide and is of steel construction. Insulating material is provided between the outer steel walls and the inner walls, which consist of oak panelling, with a special asbestos ceiling. A separate mess room with electrically-heated water supply, electric cooker, etc. is provided for the men, together with lavatory accommodation. Private and post office telephones are also installed.

The heating of the control cabin is carried out by three 4 kW heaters of the non-luminous type arranged near the contactor panels. These heaters are thermostatically controlled and are thus automatically switched on if the temperature falls below a predetermined level.

The whole of the equipment has been supplied by the G.E.C., and as the gear on the control desk is chromium plated, this finish has been adopted for the fittings of the cabin.

OPENING THE SWING SPAN.

To open the swing span, the operator first closes the shore circuit breaker by operating the appropriate switch on the desk. The closing of the breaker is indicated by a red indicating lamp on the desk (*i.e.*, No. 34 in fig. 13). The main lighting circuit breaker is similarly closed, making the supply available to

various auxiliaries and in particular to the pilot motor driving the master control drum. This motor is duplicated as a precautionary measure, and the operator must ascertain that the switch on the right of the desk has been turned to bring either one or the other into operation. A "reset" button is pressed which sets a master relay making the equipment ready for immediate operation. If the bridge is to be opened by rotating the span in a clockwise direction, the operator turns the main handwheel 90° in a similar direction; at the 90° position it will be arrested by a stop. If for any reason he wishes to carry out a partial sequence, he will of course move the handwheel only so far as to cover these operations. For this purpose eight notches are provided in each quadrant of the handwheel control, and the pointer of the handwheel passes over corresponding studs numbered 1 to 8.

For a complete clockwise opening sequence, the handwheel is turned through its full 90° travel, the upper contacts of the controller which are coupled to the handwheel spindle, are displaced to the left (see sequence diagram, fig. 14) and the "clockwise direction" pilot motor contactor closes, together with a relay determining the direction (in this instance, clockwise) in which the span will move. The pilot motor therefore drives the main drum in this direction, until arrested by the opening of the pilot contactor at finger No. 11. Meanwhile finger No. 26 has been energized, and causes the motor-generator starter on the switchboard to operate. As the motor-generator runs up to speed, its exciter voltage builds up and eventually causes a voltage contactor to close. This re-makes the pilot contactor circuit and the drum resumes its travel through the second and third steps, where it is again arrested at finger No. 12.

At the second step, the motor of the hydraulic pump actuating the bolts and wedges is connected to the main generator and accelerated up to speed, through finger No. 27. The pump, however, runs light, as its suction valves are at this stage held off their seats. Meanwhile, the main drum has moved on to the third step, changing the green traffic lights through amber to red and ringing the warning bells. The pedestrian warning lights above the footpaths at the end of the bridge also turn to red.

No further motion of the drum can take place

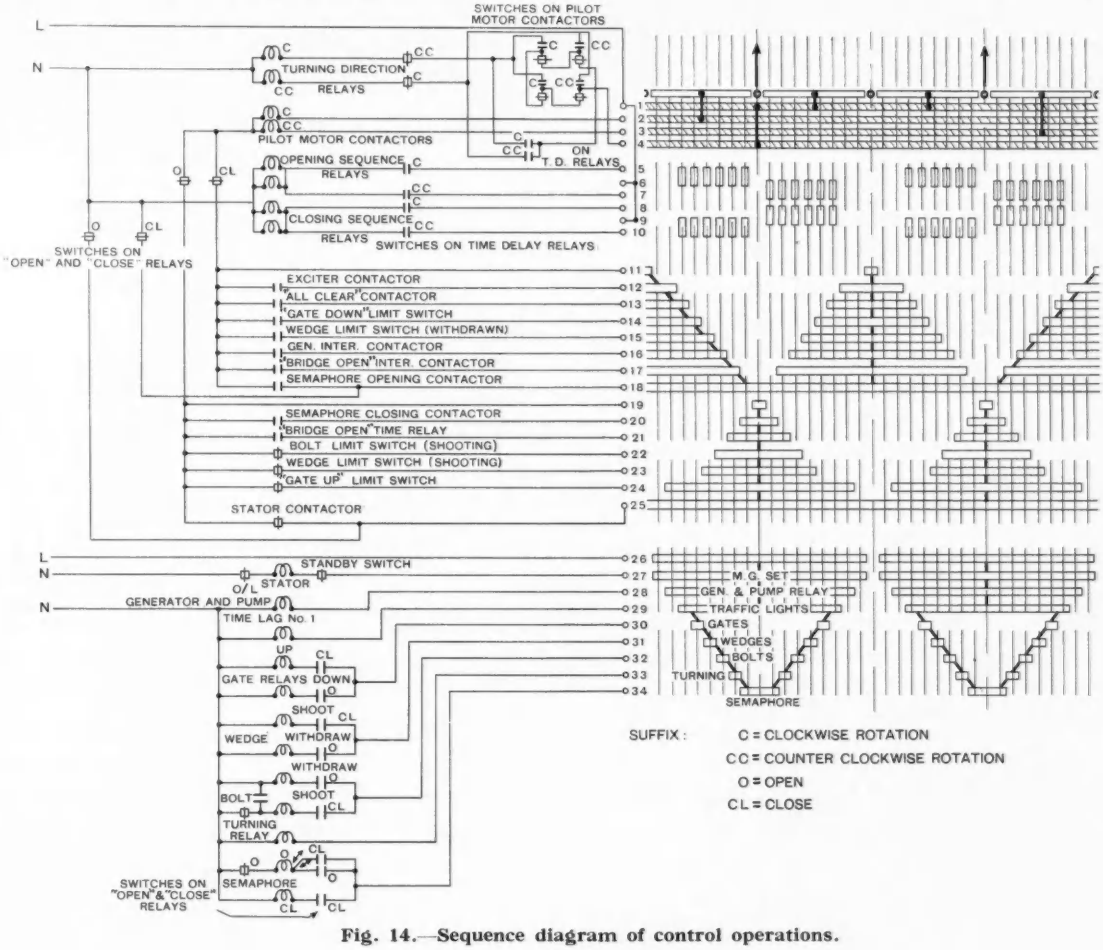


Fig. 14.—Sequence diagram of control operations.

until the assistant operator on the span roadway has made certain that all traffic is clear of the swing span, and has operated any one of three "all clear" key switches mounted near the roadway. A buzzer is also rung in the cabin to notify the chief operator. At this point contacts 5, 6, 9 and 10 bring into action sequence relays which, in conjunction with the direction relays, determine which sequence of operations will be carried out during the remainder of the controller's travel. Since the motion of the handwheel pointer is always confined to the same quadrant as that of one particular end of the swing span, the correct sequence and direction-of-swing conditions are always automatically set up to correspond with the motion of the handwheel.

The fourth step in the sequence causes the gates to be lowered, while the warning bells are silenced and one of the two semaphore arms at the ends of the jetty is lowered. The lowering of the arm indicates to the vessel waiting to pass through, that in about four minutes the bridge will be swung round to the open position. The remainder of the sequence is similar to that already described.

In the fifth step, the wedges are withdrawn by dropping the pump suction valves on to their seats by means of electrical solenoids and, by the same means, setting the reversing valves for the correct (in this instance, "withdraw") direction of travel. The bolts are similarly withdrawn in the sixth step. The pump motor is stopped and the main generator is thus free to supply power to swing the span.

During withdrawal, both bolts and wedges are under the control of the synchronizing gear described later.

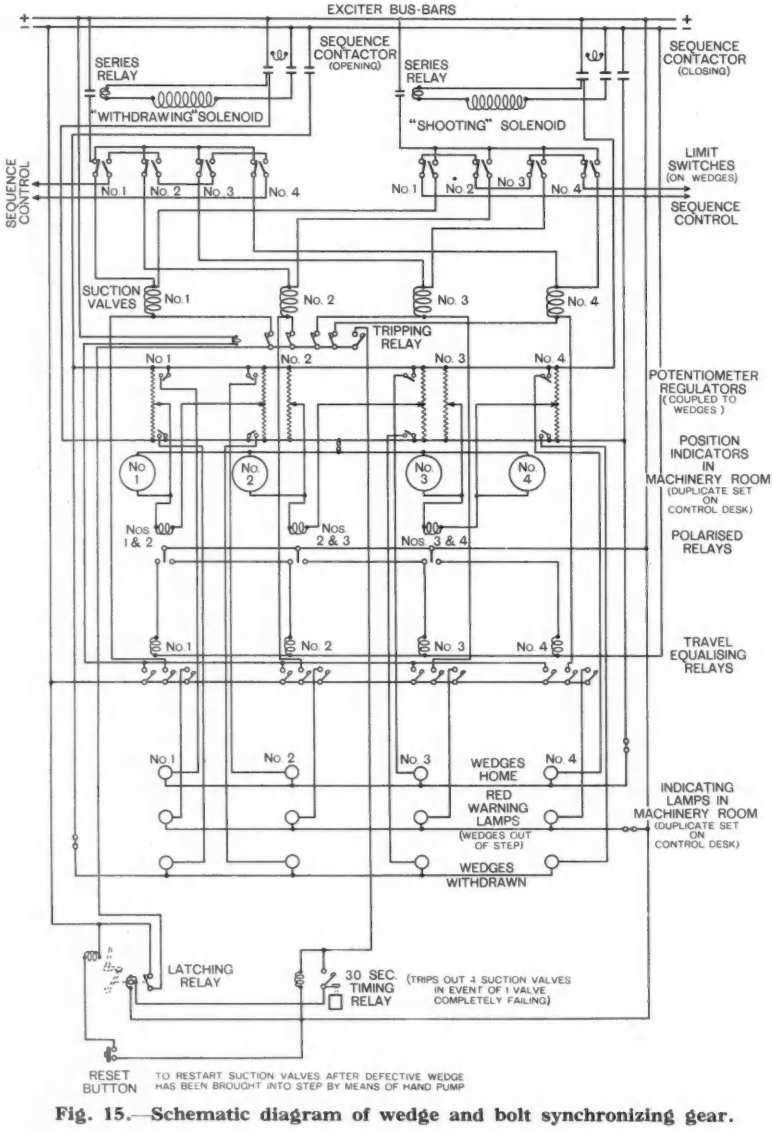


Fig. 15.—Schematic diagram of wedge and bolt synchronizing gear.

In the seventh step the span is swung into the "river open" position. First the main turning contactors close, connecting the main generator to the turning motors in parallel and lifting the brakes from the motor shafts. The excitation and voltage of the main generator is next raised gradually by a timing device, causing the turning motors to accelerate slowly to full speed. As the span approaches the "open" position, a limit switch in the machinery house initiates a very gradual deceleration of the motors, while a further limit switch opens the main circuit and allows the span to come to rest slowly under its own momentum. In order to ensure that no braking strain falls upon the span, the brakes are held off for a further period after the motors have been de-energized and are only applied when the span comes to rest. The application of the brakes then keeps the span in position and prevents any movement due to strong side winds.

The motion of the bridge may be followed in bad weather upon the indicating dial mounted on the control desk.

In the eighth and last step, the second of the semaphore arms on the jetty is operated and a short blast is sounded on the syren to indicate that the bridge is open to river traffic. For operation at night, red and amber

lights on the signal arms are used, two amber lights, one below the other, indicating "all clear" to shipping.

CLOSING THE SPAN.

The bridge is closed by moving the span in either direction, the correct direction and sequence being automatically determined by the motion of the handwheel on the control desk. The closing sequence differs slightly from the opening sequence, as the movement of the bridge now precedes the shooting of the bolts and wedges, and the working of the traffic signals.

WEDGE AND BOLT SYNCHRONIZING GEAR.

As already stated, it is important that the motions of the wedges and bolts should be synchronized. This is particularly necessary in the case of the wedges, where any marked difference in position is liable to strain the swing span structure.

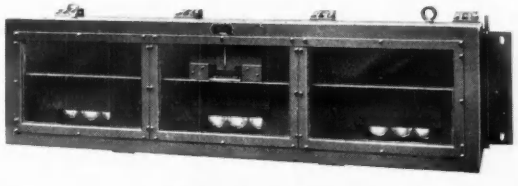


Fig. 16.—Lamp box of photoelectric aligning equipment. Note the narrow illuminated slot above the centre group of lamps. This slot corresponds with L4 in fig. 19.

The apparatus used to synchronize the wedges is shown diagrammatically in fig. 15. A similar arrangement is used for the bolts. In addition to the provision of travel limit switches at either end, each wedge drives a weatherproof potentiometer regulator through a nut-and-screw gear. One regulator at each end of the bridge is doubled, *i.e.*, it has two independent faceplates. These are needed to effect a tie between the wedges at the two ends of the bridge span. The regulators are energized from the D.C. exciter. Duplicate travel indicators are installed in the machinery room and on the control desk, and consist of voltmeters connected between one end of each potentiometer and its moving arm.

Between the moving arms of each pair of potentiometers 1–2, 2–3, 3–4, there is connected a polarized relay provided with two contacts. These relays remain in the neutral position so long as the two contact arms are connected to corresponding points of their resistances, *i.e.*, as long as the two wedges concerned are in step; a difference of 2½in. in their position, however, is sufficient to deflect the relays one way or the other.

Deflection of any relay due to the lag of a defective wedge energizes a timing relay and at the same time causes the pumps supplying the sound wedges to be shut down by having their suction valves raised. At the same time an indicating lamp marked "No. (1, 2, 3 or 4) wedge out of step" is illuminated at the control desk and in the machinery room. Pumping continues to the defective cylinder only for a period of 30 seconds: if at any time during this period the defective wedge overhauls the sound ones, the polarized relay opens circuit, and pumping is resumed in all cylinders. Simultaneously, the "wedge out of step" lamp is extinguished. If, however, the defective wedge fails to come into step during the 30 seconds allowed, all pumps are shut down and can only be re-started by pressing a "reset" button. It is then necessary for the operator to remedy the defect or, if it be a minor one, to use the emergency hand pump in the machinery room to complete the operation.

ALIGNING EQUIPMENT.

Novel and interesting arrangements have been made to ensure that the swing span is lined up

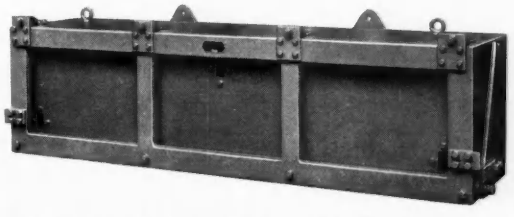


Fig. 17.—Photoelectric cell box, which is mounted at one end of the swing span.

accurately enough at the end of the closing operation for the bolts and wedges to be shot into position. It will be realized that while the position indicating dial on the control desk gives a sufficiently accurate indication of the position of the bridge for all ordinary purposes it is impossible for it to show a misalignment of a few inches, although such a misalignment would be too great to allow the bolts and wedges to be shot. Moreover, as the control room is located in the centre of the span, high up in the steelwork over the road, the operator is over 180ft. from either of the abutments and would be quite unable to see when the bridge moved into correct alignment. In bad weather, of course, any direct visual method of alignment would be inoperative. Two independent aligning systems have therefore been installed, one of which relies on the use of photoelectric cells and the other on a target light sighting principle. It should be mentioned that owing to the expansion and contraction of the bridge due to differences in temperature, and to the deflection of the ends of the span when unsupported by the wedges, the use of mechanical devices, such as limit switches, to afford correct alignment was regarded as unsatisfactory and other means, independent of variations in the dimensions of the span, had to be introduced.

The photoelectric cell equipment (figs. 16 and 17) may be understood better from the diagrams given in figs. 18 and 19. It comprises two metal lamp boxes providing fixed and unvarying sources of light and a similar box containing three separate photoelectric cells and amplifiers. The lamp boxes are mounted one on each abutment below road level, while the photocell box is mounted on one end of the swing span at the same level as the lamp boxes and so arranged that, as the span closes, the photocell box passes directly across and close to either one of the lamp boxes. An end view of the swing span showing the photocell box is given in fig. 20, and a view of

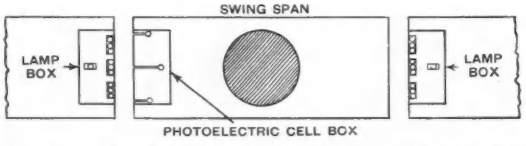


Fig. 18.—Simple diagram of swing span, illustrating relative positions of lamp boxes and photocell box.

one of the abutments on which a lamp box is mounted is shown in fig. 21. The photocell equipments are connected to indicating lamps on the control desk (Nos. 19, 24 and 25—just underneath the main position indicator) and also to two single-stroke bells.

Each lamp box, fig. 16, has three large apertures along its lower edge behind each of which are placed three electric lamps while a fourth and narrow slot aperture, illuminated from behind by a single lamp, is provided just above the central aperture. Corresponding to these apertures, the photocell box, fig. 17, has three smaller slots cut in the faceplate, two of which are at the same level as the three large apertures in the lamp box, but placed slightly wider apart, and the third is placed centrally at the same level as the narrow slot aperture in the lamp box.

As the end of the swing span approaches its alignment position the first photoelectric cell, P_3, (see fig. 19) passes across the light projected from the outer large lamp aperture, L_1. This ray of light actuates the cell causing it to operate a relay which lights the left or right hand lamp of the three mounted on the control desk. At the same time a bell will give a single warning stroke. As the span continues its approach to the central position the same photocell, P_3, passes across light apertures L_2 and L_3, each time causing the same lamp to light in the control room and the same bell to sound, thus giving a total of three distinct and separate light and sound warning signals.

Immediately after photocell P_3 passes lamp aperture L_3, the higher photocell P_2 moves directly opposite the narrow slot aperture L_4, causing the centre lamp on the control desk to light up, indicating that the span is in accurate alignment.

A slight overshooting of the span will bring photocell P_1 directly opposite lamp aperture L_1,

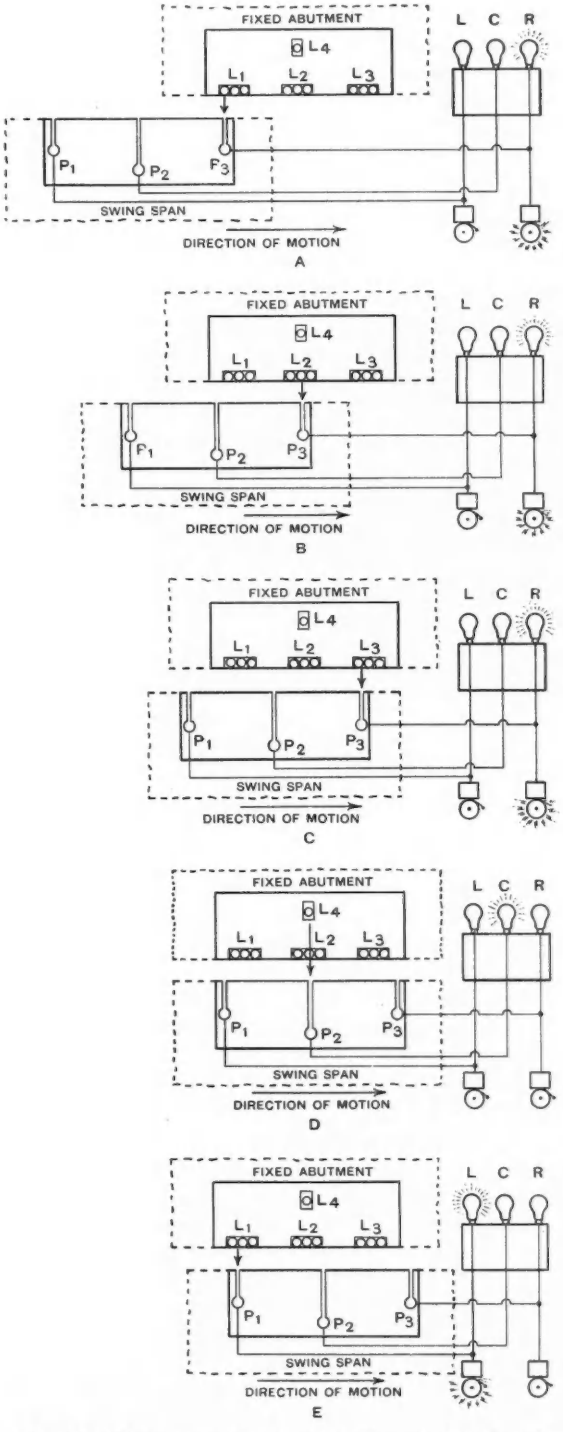


Fig. 19.—Diagrammatic representation of photoelectric aligning equipment, showing how indication is given of position of swing span relative to abutments.

which will light up the other outer indicating lamp on the control desk and cause the other bell to sound. The slightest deviation of the central photocell, P_2 to either side of the narrow slot lamp aperture L_4 causes the central indicating lamp on the control desk to be extinguished, and, therefore, so long as this lamp is alight the bolts and wedges can be closed with safety.

The construction of the lamp and photocell boxes is such that accurate adjustment can be made on site to the lamps and photocells so that correct alignment is obtained. The photocells are of the caesium type, known as Osram C.M.G.8. Each is associated with an Osram P.410 amplifying valve.

Fig. 20.—End view of the swing span, showing photocell box mounted just below level of roadway. This view also shows the bolt in the centre and the two wedges at each side.

The photocell equipment, in addition to indicating the central position of the bridge, also de-energizes the turning motors. It is evident, however, that as it is undesirable to use the brakes to bring the span to rest, the distance swung by the span under its own momentum will vary with weather conditions. In order to bring the span accurately into the central position, the operator makes use of "creeping speed" push buttons, one of which is provided for either direction. These are mounted on the desk. A further button permits the application of additional torque when "inching," should conditions make this necessary. The sequence, as before, is held up pending the working of the photoelectric centering gear. Failure of the latter would, therefore, hold up further operation of the bridge even if the span were centred visually: means are provided (in the form of a push-button in the desk) whereby the photoelectric relay may be short circuited and the sequence resumed.

The visual aligning equipment is simple but effective and can be relied upon to give accurate alignment except in very foggy weather. Of the various schemes suggested and tried out, that finally adopted consists of the following arrangement.

A vertical piano wire is fixed on the exact centre line of the bridge in the control cabin and close to the window. This forms the back sight for a target on each of the abutment portals, fig. 21, the target being a narrow vertical opal strip 5/16in. wide, illuminated fairly brightly from behind by three standard lamps. The lamps are placed about 8ins. behind the strip and are housed in a special fitting which affords easy access for cleaning and re-lamping, when required. On the upper bracing of the swing span is mounted the foresight, fig. 22, consisting of a circular frame, glazed with transparent red and green glass screens separated by a vertical gap $\frac{1}{8}$in. wide. As the span approaches its correct alignment one of the screens will pass in front of the illuminated target showing either a red or a green light to the operator, depending on which way the span approaches the abutment. At the dead centre position the white light of the target,

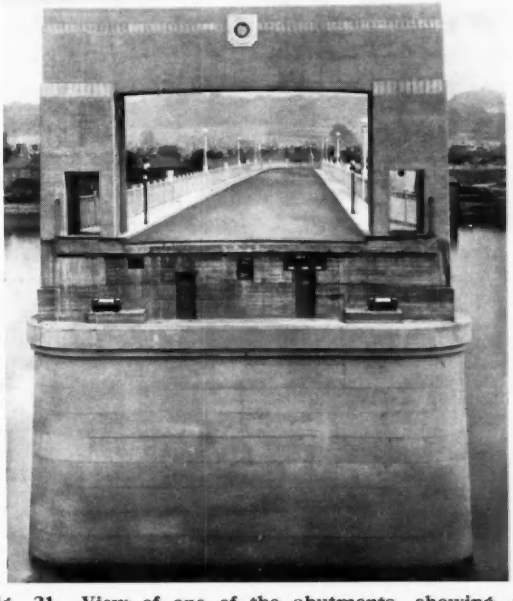


Fig. 21.—View of one of the abutments, showing the target light in the centre of the abutment portals, and the lamp box over the door on the right just below road level.

when lined against the piano wire by the operator at his desk, shines brightly through the $\frac{1}{8}$in. gap between the screens but if the span slightly overshoots the mark, the target light will again change colour as the next screen passes across it.

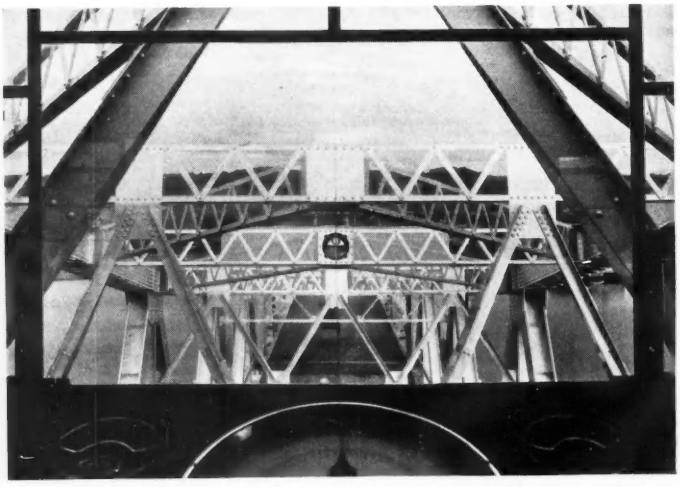


Fig. 22.—Visual aligning equipment, as seen by the operator at the control desk.

Fig. 23.—One of the electric light standards on the bridge.

It has been found that this method can be used satisfactorily by day or night.

LIGHTING.

The lighting of the roadway on the bridge and swing span is carried out by two separate systems. For the stationary sections of the bridge on each side of the span, a total of 25 decorative lanterns are installed, fig. 23, each containing a 300 or a 500 watt lamp. These lanterns have been designed to meet the requirements of the Royal Fine Art Commission for Scotland, and take the form of a complete sphere, 20ins. diameter. Each lantern comprises a heavy copper frame in which panels of morocco diffusing glass are fixed. The lanterns are mounted on columns 18ft. high, in staggered formation along the parapets of the bridge, at intervals varying from 100 to 150 ft.

It has been an important consideration in the design of these lanterns, and of those on the swing span which are of a different type and are described below, that the light emitted should be confined to the bridge and as little as possible directed towards the river. Apart from the waste of light which would occur had no special precautions been taken to achieve this end, it is important that the navigating officers of vessels passing through the swing span should not be dazzled by the brilliant lights of the bridge. Each lantern is therefore fitted with a non-axial asymmetric prismatic glass refractor in accordance with the best modern street lighting practice.

This requirement of avoiding dazzle to ships is particularly necessary in the case of the swing span. As a consequence, the roadway on the span is illuminated by six special dock-lighting lanterns similar to those installed at many important docks. These lanterns have a very efficient cut-off feature. Two of them are completely recessed into the arch forming the portals at the end of the swing span, while the remaining four are suspended from brackets in the steelwork. Each lantern is equipped with a 500 watt lamp.

In addition to the roadway lighting units, pilot lights, consisting of opal glass spheres are installed on the timber jetty running up and down stream on either side of the centre pier. These pilot lights are mounted on 9ft. cast iron columns and are used solely to indicate the exact position of the jetty to ships passing through the bridge.

In conclusion, the authors wish to acknowledge their indebtedness to Sir Alexander Gibb and Partners for some of the information contained in this article and for their kind permission to publish the drawings reproduced in figs. 1, 3 and 4.

Photoelectric Cells.

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The use of the photoelectric cell in modern industry has developed from a position of relative obscurity to one of importance, on account of the introduction during recent years of more sensitive and stable cells and of improvements in the design of suitable amplifiers.

In this article, the author first deals with the fundamental properties of the photoelectric cathode and then proceeds to discuss the relation between light and current in vacuous and gas-filled cells, subsequently indicating how these facts effect the choice of a cell for any particular purpose. Some of the simpler electrical circuits are given for measuring and amplifying the current obtained from commercial cells, and finally, examples are described of a few interesting practical applications.

THE term "Photoelectric cell" is frequently interpreted to include any device by means of which light is able to produce a change of current in an electric circuit. In a more restricted sense, it refers particularly to those types in which luminous radiation produces an electron emission from the sensitive surface and, as such, excludes cells of the photo-conductive type such as selenium, and of the rectifier type such as the copper-copper oxide and the selenium-iron combinations.

The ejection of electrons from metallic surfaces by the action of light was observed indirectly during the historical experiments of Hertz towards the end of last century. He noticed that a spark could be made to pass between two electrodes more readily if they were illuminated by another spark, or by the light from a carbon arc. Subsequently, Hallwachs proved the emission of particles carrying negative charges from a negatively charged polished zinc plate when exposed to ultra-violet rays. Elster and Geitel showed that the phenomenon could be repeated with the alkali metals and white light. Possibly the most important observation was that made later by Lenard who proved that the velocity of the ejected electrons was independent of the intensity of the light.

The expulsion of electrons from surfaces by external radiation takes place by reason of the fact that energy tends to be absorbed from the incident beam by the free electrons in the metal. If conditions are favourable, the energy received by the electrons is sufficient to project them across the surface layer and beyond the field of the restraining forces tending to pull them back into the metal.

The observation of Lenard, previously mentioned, was inconsistent with the wave theory of light. A more intense light beam, which denotes a more intense electric field, would be expected to abstract electrons with higher velocity. This discrepancy was explained by the application of Planck's Quantum Theory by Einstein. The Quantum Theory assumes that energy is not conveyed continuously but in small quanta or lumps, like bullets in the fire from a machine gun, and that the energy quantum is proportional to the frequency of radiation, *i.e.*, equal to Lv, where L is a constant, equal to 6.54×10^{-27} erg secs. and v is the frequency. Assuming that conditions are favourable for a free electron to absorb a quantum of incident energy, and that it is projected across the boundary layer, becoming a photoelectron, the kinetic energy of the photoelectron equals

$$Lv - p \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

where p represents the work which has to be expended in overcoming the restraining surface forces. If $Lv < p$, the electron obviously can never escape from the metal at all. Hence it is clear that for any given metal in which p is a constant peculiar to that metal, there is a lower limit of v for which no photoelectric emission is possible. However intense the incident radiation, no photoelectrons will appear unless there is some energy in the beam of frequency high enough to satisfy the relation

$$Lv = p, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

which is the threshold frequency for any particular substance whose work function is p.

Taking the extreme limits of the frequency range of common experience, we find that for radiation where λ is of the order of 10^3 cm., *i.e.*, wireless waves, no substance exists whose p satisfies the relation (*ii*) so that photoelectric emission cannot be excited in any material by radiation of this kind. At the other extreme, where λ is of the order of 10^{-8} cms., *i.e.*, X-rays, the work function of every element is small enough to satisfy the relation, *i.e.*, electron emission always takes place by the incidence of X-rays. Between these extremes of frequency, in the comparatively narrow band 0.4μ—0.8μ, *i.e.*, the visible spectrum, there are seven elements *Na, K, Sr, Rb, Cs, Ca, Ba*, whose work functions all satisfy the relation (*ii*) and can therefore be used as photoelectric cathodes for ordinary white light. The exact threshold frequency is not generally determinable with great accuracy on account of the enormous

effect of small quantities of adsorbed gas, but results obtained show evidence that the thermal and photo-electric work functions are in close agreement with each other. It is of interest to note that the elements which show photo-sensitivity in the visible spectrum are those which have but one electron—two in the case of *Ba, Sr,* and *Ca*—in the outermost ring of the atomic structure and it would appear that this electron is loosely held to the parent atom and

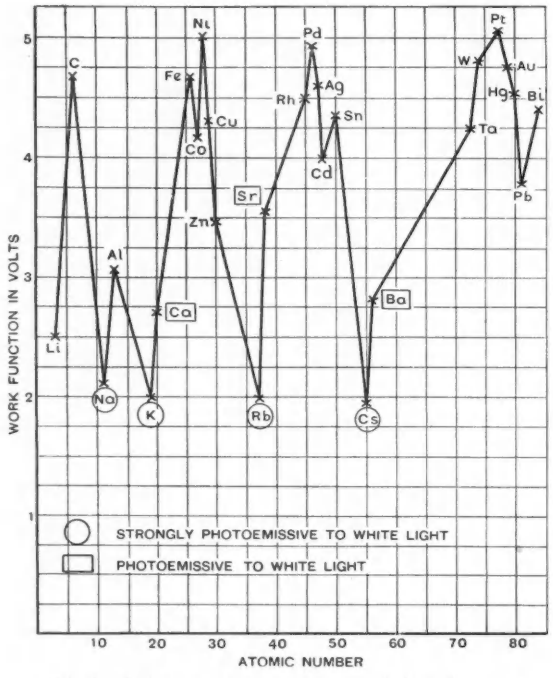


Fig. 1.—Relation between the work function and atomic number for various elements.

accounts for the low work function of these elements. This is made clearer by fig. 1. Before the advent of modern photoelectric cells having composite layer cathodes, plain metallic surfaces of the alkali metals, usually potassium, were employed. The affinity of the metal for oxygen necessitated the whole preparation of the emissive surface being carried out in an evacuated bulb. The metallic surface was prepared by condensing the distilled metal on to a suitably prepared supporting plate and subsequently activating the surface so formed by filling the bulb with hydrogen and passing a discharge between the electrodes—a process which was used soon after the evolution of the earliest type of cell. The hydrogen was subsequently removed and the evacuated bulb sealed off.

As instruments for industrial use, the now obsolete types of mass layer cathodes had many disadvantages. Their sensitivity to all usual forms of artificial illumination was low and was liable to deteriorate suddenly from unexplained causes, and comparatively slight rise of temperature was sufficient to distil off the cathode completely. Except for a few very special purposes, they have now been entirely displaced by the composite layer cathodes, consisting of a thin stratum—of the order of one atom in thickness—of an alkali metal deposited by suitable heat treatment on an oxidized metal electrode, usually copper or silver.

The spectral sensitivities of the thin layer cathodes, which are free from serious change in characteristics due to temperature variations—a material advantage over some other light sensitive devices, such as the rectifier cell—are entirely different from the mass layer cathodes of the same metal, and the nature of the surface on which they are deposited also plays a definite part in determining the response. The peak response of the thin layer cathodes is in every case displaced toward the region of long wavelengths, as compared with the mass layer of the same metal, and so approaches more nearly the region of maximum energy of radiation from artificial sources. Hence, cathodes of this type are enormously superior in all cases except those involving a preponderance of short wave radiation. In the blue end of the spectrum the potassium or sodium cell of the older type is still preferable and

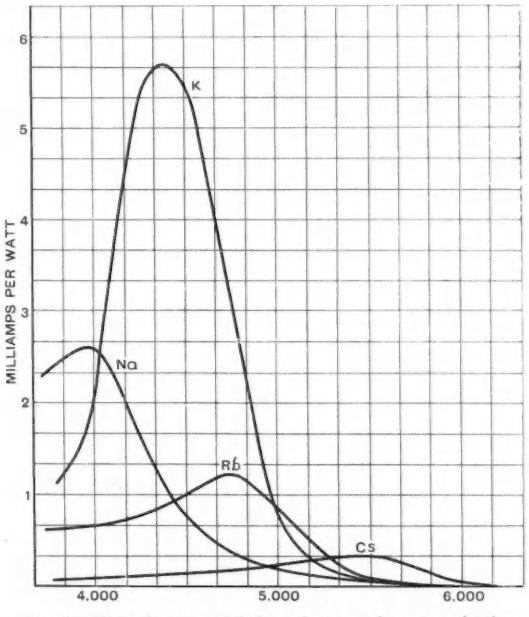


Fig. 2.—Relative sensitivity of mass layer cathodes.

in this connection it is desirable to compare figs. 3 and 4, which show the relative sensitivities of the two typical cathodes taken under different conditions.

VACUUM CELLS.

For a given light flux incident on the cathode, the number of electrons which reach the anode will increase as the applied potential is raised to about 20 volts, after which $\frac{dI}{dV}$ becomes very small as V

increases. In general it may be considered that current saturation is practically complete at this point. Under these conditions, the ratio of photoelectric current to luminous flux for light of the same spectral distribution is constant. Vacuum cells are essentially precision instruments and are always preferable to the gasfilled type except where detection is the only object in view. A symmetrical arrangement of electrodes characterizes a good vacuum cell, and internal and external guard rings are usually provided to shunt surface leakage currents when making precision measurements.

GASFILLED CELLS.

The characteristics of a cell are altered enormously by the introduction of an inert gas at suitable pressure into the glass envelope. As the potential difference across a gasfilled cell is raised, the electron velocity also increases. At first, the collisions between the electrons and the gas particles are elastic, but with increasing velocity they become disruptive, and sufficiently violent to eject one or more electrons from the gas atoms. These displaced electrons in their turn, eject others, and all of them join in the main stream, so that the total number reaching the anode is greatly in excess of that leaving the cathode. Moreover, the positive ions which remain are driven back on the cathode and by impact produce a further electron emission which is independent of the incident light. If the potential difference is high enough, the current due to this cause may rise enormously and become visible as a blue glow in the cell. If it is not restricted by resistance, or if allowed to pass too long, this discharge will invariably destroy the cathode. The precise nature of the current change when the glow discharge appears, depends to some extent on the intensity of illumination. For low illuminations, the relative increase is very large; with more intense illumination the transition is less sudden and the relative increase smaller.

In spite of the ultimate destructive nature of the discharge, it is interesting to note that a momentary discharge gives rise to an increase of sensitivity in mass layer cathodes and was used quite early in their history as a method of sensitizing them.

When once started, the glow discharge will continue, even with the light source removed, until the potential difference is reduced considerably below that which initiated it. The glow potential is not a constant of the gasfilled cell and is lower the higher the illumination. Hence, in practice, if the cell is exposed to large variations in light intensity the potential applied must not exceed the safe limit for the maximum illumination.

An important characteristic of the gasfilled cell is the "slope" which is defined as $\frac{1}{I}\frac{dI}{dV}$, where I is the photoelectric current at the applied voltage V. This term is practically independent of the illumination, and its value which lies between 2 and 10 per cent, indicates the proximity of the cell to its glow discharge point, and determines the highest gas magnification which can be applied to the cell with safety.

From what has been stated it will be clear that strict linearity of response is possible only with the

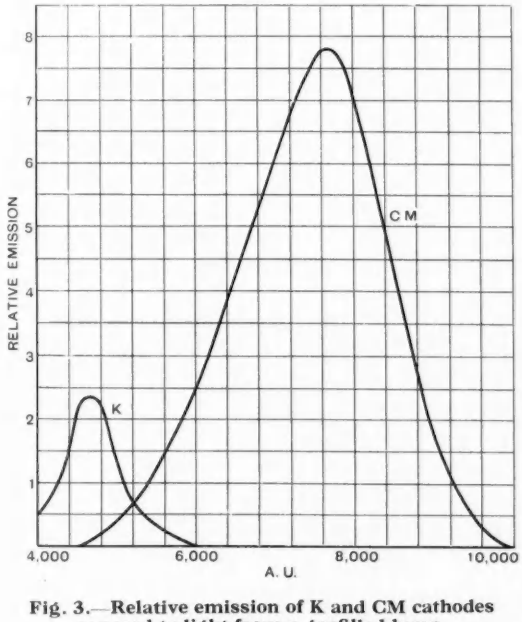


Fig. 3.—Relative emission of K and CM cathodes exposed to light from a gasfilled lamp.

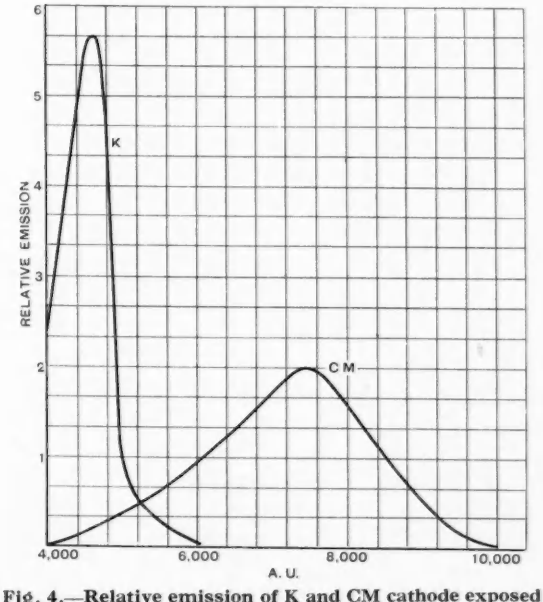


Fig. 4.—Relative emission of K and CM cathode exposed to a source having uniform energy distribution.

vacuum type of cell. Frequently, high sensitivity and linearity of response are both demanded, and the use of the gasfilled cell with low magnification is an attempt to secure a compromise between these two characteristics which are to some extent mutually exclusive. Such demands have hitherto been put forward for sound film projectors. Hence, it has been common practice to specify the conditions

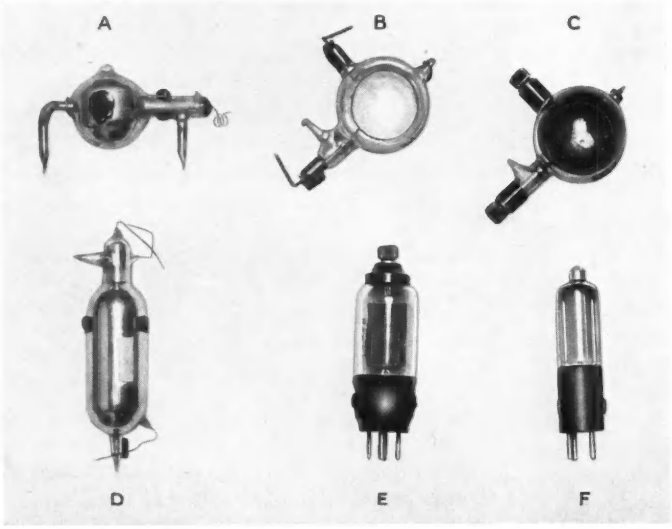


Fig. 5.—Group of photocells showing development from the earliest type (A), to the most recent form (F).

under which each cell will give its most satisfactory performance both in respect of sensitivity and frequency response, by indicating its "working voltage" under certain specified conditions of illumination. The "working voltage," therefore, has a wider significance than merely that of the potential applied between the electrodes, and is intended to indicate the potential at which there is a specified increase in primary current due to gasfilling under a stated illumination. Under these conditions, the ratio of photoelectric current to primary current is known as the gas factor, or gas magnification. In the range of audible frequencies, the limit of the gas factor is about 10. Higher magnification leads to perceptible distortion and with the advent of high fidelity recording the tendency is to restrict the gas factor to much lower figures, usually about 3 or 4.

Improvements in the technique of cell manufacture, and the recent production of cathodes with considerably greater average primary emission—25 to 35 μA/lumen as against 10 to 15 μA/lumen hitherto available—enables the manufacturer to meet the demands for higher fidelity in reproduction without any sacrifice in sensitivity. Hence, development shows that the gasfilled cell is becoming of less importance and its advantage over the vacuum cell in industry may eventually disappear.

DESIGN OF CELLS AND TYPES IN USE.

Since the photoelectric current in practice rarely exceeds a few microamps, and is generally very much less, the design of cells calls for particular care in avoiding insulation leakage. The length of glass surface separating the cathode and anode should be maximum. Other things being equal, it is clear that a construction in which the electrodes are brought out at diametrically opposite points has an enormous advantage in this respect. Commercial considerations, however, frequently demand the less satisfactory construction of a single-ended cell. Consequently, particular attention must be given to the insulation resistance of the cap and the holder into which it is to be fitted, and should in no case be less than 1,000 megohms.

For practically all industrial uses the C.M. type of cell is universally employed. Its sensitivity curve for all practical purposes ceases at about 1·1μ though, with delicate means of detection, response up to 1·3μ can be found.

The ability of the cell to respond to the shorter infra-red rays enables commercial apparatus to be operated in some circumstances with invisible rays. As a source of such rays, a projector lamp with an infra-red filter may be employed, but the arrangement is inefficient in view of the fact that the greater portion of the useful radiation is absorbed by the filter (*cf* fig. 3).

For radiation of the kind which permeates rock salt, and which is generally implied by the term "infra-red" rays, photocells of any kind are, and probably always will be quite useless. Potassium or sodium (mass layer cathodes) in hard or corex glass bulbs can be used in the near ultra-violet spectrum, and for shorter wavelength radiation in this range the cadmium cathode in a glass bulb with a quartz window is employed, the window being attached to the bulb by a gas tight sealing wax joint. It is common practice to avoid the use of an expensive quartz bulb, which is difficult to work. Since the application of heat to the quartz window to prevent condensation of the metal is not permissible, a thin glass disc is sealed into the bulb to cover the window during the preparation of the cathode. This disc is subsequently shaken down into the well of the bulb and the clear window exposed. Cells of this type are invariably fitted with external and internal guard rings.

USE OF CELLS.

In only comparatively few instances are cells used for the sole object of the measurement or detection of radiation. In general, it is merely an intermediate, or indirect process to gain information

about a variable whose changes can only be measured directly with difficulty, but whose relation to absorption, or transmission of radiation of specific wavelength is known. If the rate of growth of bacteria in a culture medium is a function of the absorption of monochromatic light of a specific wavelength, the growth can obviously be measured by a photoelectric cell, but if no such relation can be established no good purpose is served in employing photoelectric methods.

In practice, cells are used as a means of measurement, comparison or detection. If sufficient light is available, the simplest possible circuit using a vacuum cell in series with a galvanometer and battery of about 20 volts, may be employed for direct measurement. Alternatively, a compensation method may be used where the photoelectric current is balanced by a potentiometer and fixed resistance, so that the photoelectric current is measured absolutely in terms of potential and resistance (fig. 6), or may be balanced against the current from another photocell excited from the same light source, the conditions of balance being then independent of the variations in the light source.

The high internal resistance of the emissive type of cell makes it applicable to electrostatic methods of measurement in which the photoelectric current may be estimated in terms of the rate at

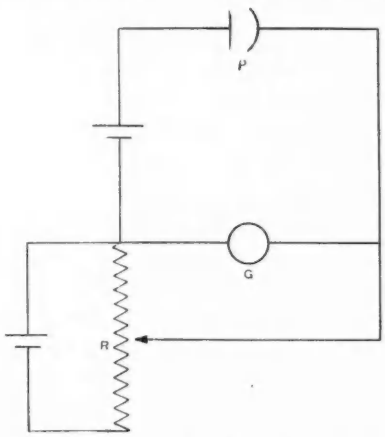


Fig. 6.—Diagram of connections for compensation method of measurement by means of a photoelectric cell.

which it charges a condenser (fig. 7), a method which is useful where the current is limited. Methods using this principle have hitherto used the electrometer as an indicator, but this has to a large extent been displaced by the valve voltmeter. The measurement of feeble illuminations in this way is limited by the insulation resistance of the components and the photoelectric current is found in terms of the rate of potential rise across the condenser and is equal to $C\frac{dE}{dt}$.

Measurement usually demands a linear relation between the amplified and the photoelectric currents, and the applications of television, phototelegraphy and sound reproduction, come strictly under this heading. Fortunately, acoustic reproduction does not involve strict linearity since the sense of hearing is sufficiently defective to be able to tolerate a certain amount of distortion without perception.

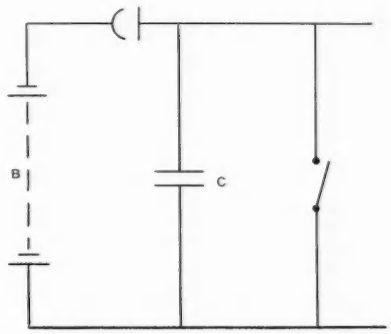


Fig. 7.—Diagram of connections for electrostatic method of measurement by means of a photoelectric cell.

AMPLIFICATION.

The foregoing methods by their nature, are, in general, quite unsuitable for industrial applications. The low magnitude of the photoelectric current—not more than a few microamps can ever be taken from the C.M. type cell continuously without altering its characteristics—make any method of amplification extremely desirable.

If the amplification is very high, as in television transmission, the elaboration of the amplifier to secure an approximately linear output is very considerable. This is, of course, mainly a problem of amplifier design and need not concern us further here, and attention need be paid only to the pre-valve circuit. This example is, however, indicative of the general principle that the use of a multi-stage amplifier employing commercial valves for the linear amplification of feeble photoelectric currents may involve too much elaboration for industrial use.

Fortunately many of these difficulties can often be avoided by the use of balanced bridge circuits or by the employment of the electrometer triode, and the unit which combines this triode with a photocell in an evacuated envelope.

A typical pre-valve circuit for coupling the photocell is shown in fig. 8. This would be applicable to any case where the same general principles as are involved in sound reproduction are present and where the incident radiation fluctuates at audio or higher frequencies. C_1 represents the unavoidable capacity of the photocell, and C_3 the inter-electrode

capacity of the valve. The impedance between the points $XY = \sqrt{\frac{1}{\frac{1}{R_1^2} + (2\pi nC_1)^2}}$ and with current i represents a potential difference of $\frac{iR_1}{\sqrt{1+(2\pi nC_1R_1)^2}}$

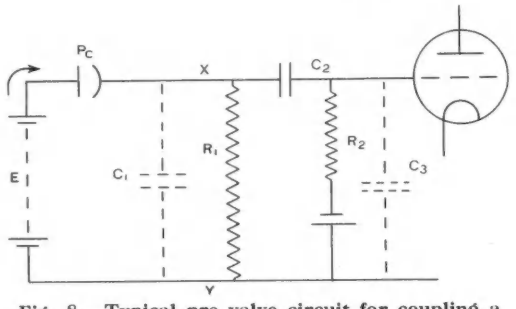


Fig. 8.—Typical pre-valve circuit for coupling a photocell.

The potential across XY is independent of n only as long as $2\pi nC_1R_1$ is small compared with unity. Hence, as n increases, the importance of reducing C_1 becomes apparent. In practice the cathode, which is the larger electrode, would be connected to earth and a cable of low capacity must be used to couple the cell to the amplifier.

From considerations of the valve circuit the inter-electrode capacity C_3 must be small, and the resistance R_2 low enough to prevent grid current

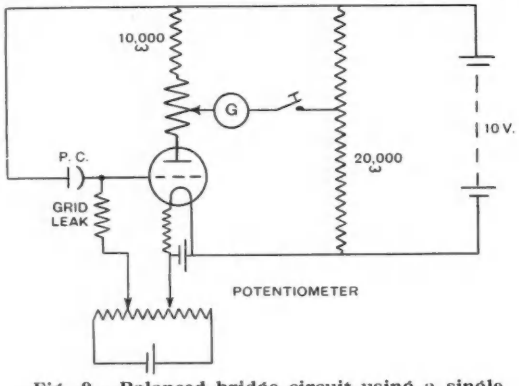


Fig. 9.—Balanced bridge circuit using a single valve.

setting up appreciable potential difference across it. Since C_2C_3 form a parallel circuit to C_1, C_2 must obviously be small to avoid increasing the effective capacity of C_1. At the same time, the time constant C_2R_2 must be high compared with the period of one alternation of the incident light. These requirements are obviously mutually exclusive so that the theoretical conditions for optimum efficiency cannot be obtained. Unless distortion is introduced and corrected in subsequent stages, it is usual to be satisfied with a relatively low amplification in the first stage and make the pre-valve circuit a mere coupling between the photocell and the first amplifying valve. In sound projectors R_1 is usually about 0.5Ω, and C_2 $0.01\ \mu F$. Increasing R_1 increases the gain to a limit set by the insulation resistance but makes the frequency response worse.

In practice, the maximum amplification is set by the noise level of the valve and the introduction of valves of the A537 class has materially improved the attainable efficiency of the first stage.

Balanced bridge circuits in which numerical readings are made on a calibrated potentiometer[1], have also been employed, and elaborations of this principle involving the electrometer triode[2] are now in use for quantitative estimation of illumination. Originally two valves were employed and the indicating galvanometer connected between the resistance arms in the anode circuits of the valves to show a condition of balance. Potentiometer control of the grid bias of one valve enables the galvanometer deflection to be brought back to zero for each illumination on the cell. Later circuits, *e.g.*, fig. 9, dispense with the second valve and use a resistance to secure the condition of balance. It is possible in this way to calibrate the potentiometer in terms of light intensities on the photocell over a considerable range.

It is usually an advantage if a problem involving quantitative estimation can be converted into one in which the amplifier plays the part of a comparator in establishing an equilibrium position. This is exemplified in the type of instrument in which comparisons are made between light reflected from two different surfaces. The reflected light from each surface in turn and in very rapid succession is directed by means of a rotating shutter on to the photocell. Any inequality in the two illuminations is amplified and the output current caused to actuate a shutter which gradually cuts off the brighter of the two beams until equality is attained, and there is no fluctuation in the photoelectric current and no current change in the output stage. This condition of balance is at the same time recorded by means of a marker on a chart and the comparison is then repeated for monochromatic light of some other wavelength till the whole spectrum, or any required portion of it is covered. In this way a chart giving some co-relation can be obtained between the selective reflection between the two surfaces. The principle of the method used is important because its accuracy in no way depends on the amplifier characteristics since only the condition of "no input" is detected and any inaccuracy due to variation in valve characteristics is automatically eliminated.

(1) "The Design of Precision Commercial Photoelectric Photometers," G. T. Winch and C. F. Machin, G.E.C. Journal, Vol. VI, No. 4, Nov., 1935.
(2) "The Electrometer Triode and its Applications," G. W. Warren, G.E.C. Journal, Vol. VI, No. 2, May, 1935.

TRIGGER CIRCUITS.

The great majority of industrial applications do not, fortunately, demand conditions which involve the difficulties of linear amplification previously mentioned. In most cases, mere detection is required and is very easily met by simple and efficient apparatus. The ultimate object usually is to close or open a controlled circuit when a specified change in illumination on the photocell takes place, the change being frequently from a maximum to zero, or *vice versa*.

The photoelectric current can be made to change the potential of the grid circuit of a thermionic valve, and start or stop the anode current. The incidence of light on the cell may (1), reduce the negative bias of the grid to a less negative value, or (2), change the grid potential from a positive or zero value to negative.

The circuits to incorporate either of these operations are very easily adapted for operation from supply mains.

Fig. 10 shows the mains circuit involving operation (1), and fig. 11 operation (2). In both of the cases shown, the valve filament is connected in series with resistances across the mains, the resistances being sub-divided to give appropriate values of potential difference to the anode of the valve and the photocell. In fig. 10, the grid of the valve is biased negatively by the potential difference across R_2, and the anode current is zero. Incidence of light on the photocell reduces the bias and allows current to pass through the relay in the anode circuit. In fig. 11, practically the reverse action takes place. In the second case, the grid and filament are at the same potential when the cell is dark, and current passes in the relay in the anode circuit. The incidence of light on the cathode of the photocell produces an emission which first neutralizes the valve grid current and then establishes a negative potential on the grid, reducing the anode current to zero. Since the intensity of light required to reduce the grid potential to zero is greater than that necessary to maintain it in this condition, there is some difference between the illuminations required to switch the relay from the "on" to the "off" position, and *vice versa*, a condition which is favourable to the maintenance of stability of operation. The circuit also has in general the merit of higher sensitivity than that involving operation (*a*).

The grid leak, which is normally of the order of 10 megohms, restores the grid to its original potential when the light is removed.

If A.C. is substituted as a source of supply, the potential applied to the anode of the valve and the photocell cathode are of opposite phase, so that during one half of the cycle the conditions are the same as on D.C. Consequently, if the relay can be made to overhang the negative half cycle during which the current through it will be zero by reason of the rectifying action of the valve, the operation of the circuit will be satisfactory on this type of supply. To secure this conditon, the telephone

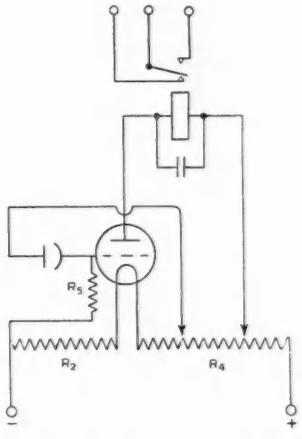


Fig. 10.—Mains circuit in which light on the photocell reduces the negative bias of the grid.

relay coil must be shunted by a large condenser otherwise it will chatter.

If the relay is suitably adjusted, both these circuits can be made to operate satisfactorily for slow changes of illumination where the trigger action of the circuit is less pronounced.

The only merit of using resistances in the filament circuit is that the set can be used for A.C. or D.C. indiscriminately, but heating of the resistances

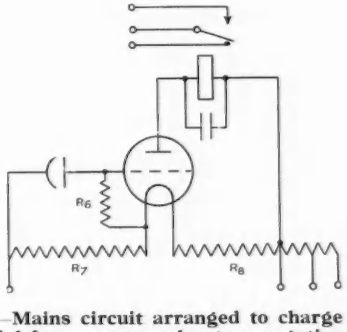


Fig. 11.—Mains circuit arranged to charge the grid potential from a zero value to a negative value.

restricts the valve used to one of the minimum filament current rating, *i.e.*, the L21 class. Either circuit is more economically and equally satisfactorily operated from A.C. through a transformer with suitable windings to give the voltage division indicated in the figure.

The effect of the resistance R_6 on the sensitivity and time lag of response of the relay is interesting. Obviously this time lag cannot be less than its specified

pick-up time but may be restricted by other considerations. If it is assumed that the resistance of the grid leak in fig. 11 is infinite, the grid current curve of the valve is represented by curve ABCD, fig. 12, and the point A will indicate the state of zero grid current.

When the photocell is illuminated, the grid becomes more negative until the photoelectric current is balanced by the current carried by the positive ions, a condition indicated by the point B. A further increase in illumination establishes the condition indicated by the point C, where the backlash is a maximum. Further increase in illumination cannot be balanced by positive ion current, and the grid takes up the potential difference across resistance R_7. The anode current falls gradually (curve a_1 fig. 13) until the point c_1 is reached after which it is discontinuous. If the insulation were perfect the grid would be maintained at this potential and the circuit could not reset.

The effect of the Grid Leak.

A high resistance leak R_6 modifies the grid

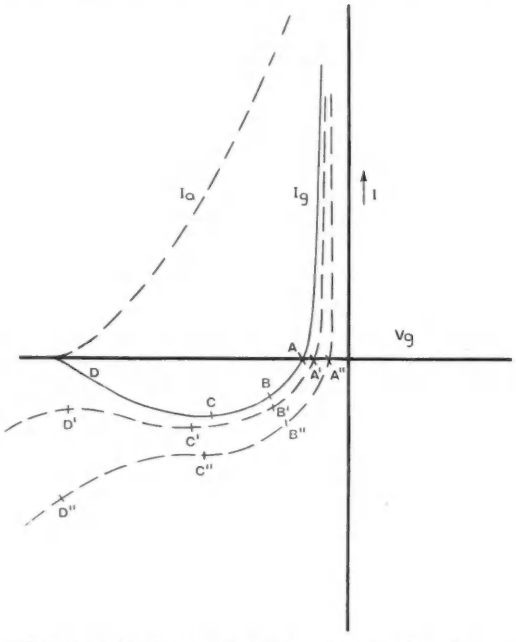


Fig. 12.—Variation of grid current with voltage for different values of grid leak resistance.

current curve to A′ B′ C′ D′ so that a slightly higher illumination is required to cut off the anode current, the corresponding photoelectric current being shown by the ordinate C′ (fig. 12). When the photoelectric current exceeds this value, the anode current is reduced to zero as before. If, however, light is now removed, the original grid potential is restored by the leak R_6. Reducing the value of R_6 still further gives rise to the corresponding curve A″ B″ C″ D″ and there is no discontinuity in the anode current curve (fig. 13 curve a_3). In this case the photoelectric current required to reduce the anode current is now the ordinate of D″. Hence it is clear that sensitivity and time lag both increase with increase of R_6. Practical considerations usually limit R_6 to 10–20Ω unless precautions are taken to maintain very high insulation elsewhere, and the ultimate time of response is therefore set by the design of relay in the anode circuit.

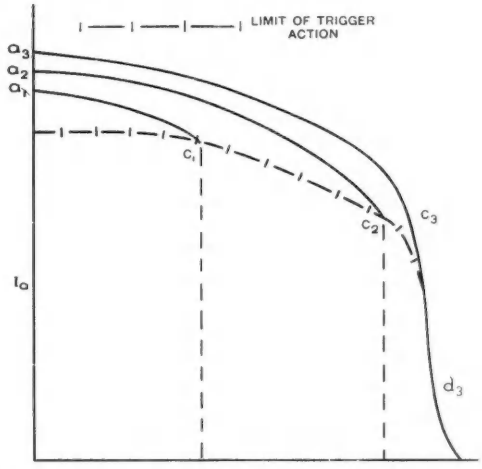


Fig. 13.—Variation of anode current with illumination for different values of grid leak resistance.

It is clear from examination of fig. 13 that continuity of the anode curve is secured only by reducing R_6 to a value which considerably impairs the sensitivity and that, even so, no appreciable portion of the curve is linear so that the circuit is obviously unsuited, apart from other considerations, for making quantitative measurements. Neither circuit permits of satisfactory adjustment internally to secure variation in sensitivity, but this requirement is easily met by an adjustable window covering the photocell.

OTHER CIRCUITS.

For practical applications of light sensitive cells which demand higher sensitivity, recourse may be had to:

(1) D.C. coupled circuits suitable for slowly recurring cut-off.

(2) Gasfilled relays[3] with or without one or two pre-stages of valve amplification.

The latter are exceedingly useful for cases where the cut-off is of the order of a milli-second.

Fig. 14 shows such a circuit involving two preliminary stages of valve amplification. The arrangement is one of extreme sensitivity to feeble illumination of rapid cut-off. Some idea of its capabilities can be gathered from the fact that it

(3) "Gasfilled Relays"—S. K. Lewer and C. R. Dunham. G.E.C. Journal, Vol. III, No. 2, May, 1932. No. 3, Aug., 1932.

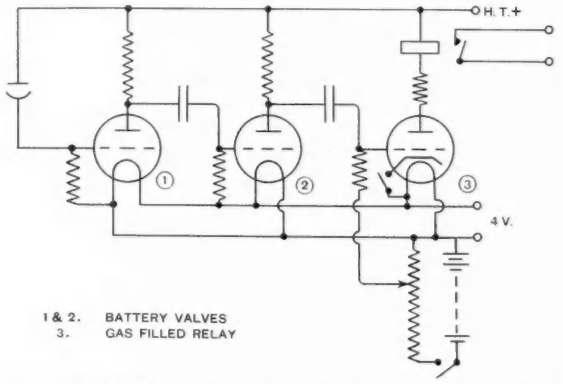


Fig. 14.—Resistance-capacity coupled circuit employing a gasfilled relay and two preliminary stages of valve amplification.

has been employed to detect pin-holes of the order of 0.1 mm. diameter in sheet metal moving at the rate of 70cm./sec. representing an impulse of less than a milli-second. The inclusion of the gasfilled relay necessitates the provision of an independent resetting device to stop the anode current and this may conveniently be included in the cathode lead. Since the couplings are capacitative, the circuit is sensitive only to rapid changes in illumination and need not therefore be elaborately screened against stray light of constant intensity. Since the change in illumination to be detected must give a positive impulse to the grid of the gasfilled relay, the impulse to the first grid must also be positive if the number of valve stages is even and the change to be detected one of sudden illumination. The photocell would be reversed for a reverse detection, or for the same detection with an odd number of valve stages.

For simple trigger circuits which do not involve short detecting periods or rapid repetition, the gas-filled relay has no particular advantage over the hard valve and small contactor.

APPLICATIONS OF CELLS.

The most extensive use of the alkali metal cell is in the sound reproducing field. The general principles involved in this application can be considered as common knowledge. The improvements in the fidelity of recording have left room for improvement in reproduction, which has resulted in the tendency to market cells with lower gas factor, as previously mentioned, to meet the demand for an improved frequency response. The British Standard Specification now imposes a limit of 5 decibels fall in output over the range of 50 to 1,000 cycles, and 5 decibels over the range 1,000 to 10,000, or 8 decibels over the whole range 50 to 10,000 cycles. It is interesting to note, however, that in recording the upper frequency range, the actual record of one period on the film approaches the dimensions of the slit and the wave forms of the upper frequencies must differ widely from those of the lower range. It is common practice to test frequency response by means of a frequency film passing across the slit at constant speed, whereas to eliminate the wave form variable, the test would appear to require one and the same record to be run at variable speeds.

The sound film has found many applications outside the world of entertainment, particularly for repeating warning of the opening and closing of lift gates, for announcing the record of automatic weighing machines, etc. Installations of apparatus for the former purpose are in operation at the Strand and Earls Court Underground stations. Experimental equipment has also been used by the Post Office to give audible indication of the state of telephone lines to subscribers to eliminate the confusion which sometimes exists in interpreting the meaning of the various signal tones which are in general use on automatic telephone systems.

Closely allied to the general use of the photocell for reproduction of recorded sound is its use as a means of producing synthetic tones and as an audio frequency generator of variable wave form. If the light from a steady source falling on a photocell is interrupted by a rotating perforated disc, the holes in which are equally spaced a diameter apart, the resulting photoelectric current is approximately sinusoidal in outline. Alternatively, the apertures in the disc can take the form of narrow rectangular strips and sweep across a uniformly illuminated silhouette of the sine wave, the transmitted light being focussed on to the photocell. Obviously, the arrangement can be used with a masked outline of any wave form and by varying the speed of the rotating disc constitutes a source of audio frequency vibrations whose wave form can be changed at will.

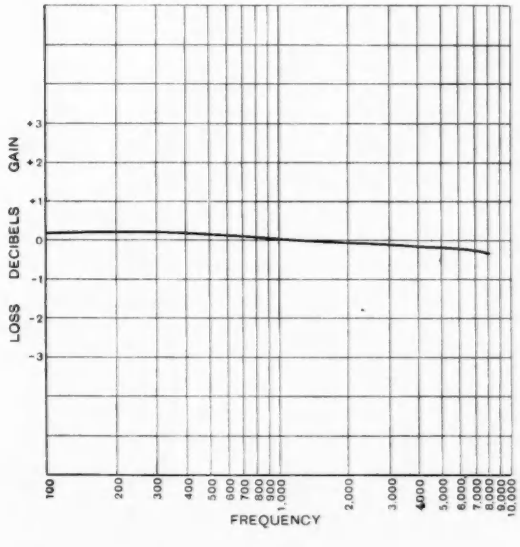


Fig. 15.—Variation of output in decibels with frequency (CM type of cell).

In testing amplifying equipment, this arrangement has the advantage over other well-known audio frequency generators that the wave form of the injected E.M.F. is known exactly and may readily be altered. The wave form at any stage of the network under examination can be depicted by means of the cathode ray tube and a direct comparison made with the injected E.M.F. at the input stage, so that amplitude or phase distortion introduced at any stage is definitely known.

A musical instrument covering the whole band of audible frequencies and incorporating tones of as many wave forms as are desired can be constructed by using an elaboration of this principle and forms the basis of the all-electric pipeless organ. Each frequency necessitates a ring of slots and a mask of each wave form to be reproduced, the number of slots in any ring being proportional to the corresponding frequency. Transmission of light from a suitable optical source through any particular circle of slots is effected by means of a shutter controlled by the corresponding "note" on the manual and the whole range of frequencies for any one particular wave form, or number of wave forms, are brought under the control of the manual by the withdrawal of the corresponding "stop" which completes the appropriate lamp circuit.

An instrument constructed on these principles has many advantages over the familiar pipe organ, particularly in respect of cost and space occupied; also there is the great merit of being able to place the loudspeakers in positions suitable to the natural acoustic properties of the hall in which reproduction is to be delivered.

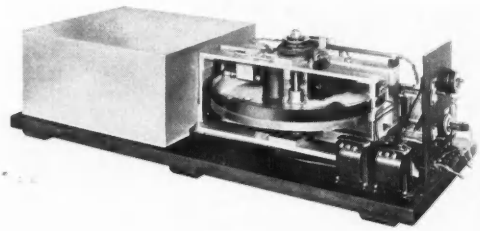


Fig. 16.—Experimental line announcer used by the G.P.O.

Other advantages are the ease with which rising or falling volume can be produced by resistance control of the lamp circuit and the inability of individual notes to get out of tune since their frequency ratios are fixed, the general level being adjustable by speed control of the driving motor.

Space permits of but brief reference to the many industrial applications involving the use of the trigger circuits previously described, where the photocell merely plays the part of a switch to which there is no direct contact by the objects in the controlled process. For instance, the counting of objects on a conveyor belt may preferably be carried out photoelectrically if the objects are of all shapes and sizes, or are extremely light, under which conditions the operation of a mechanical counter would be less positive in action. Selection by means of the disposition of the optical source is also frequently useful. In conjunction with a neon lamp and condenser timing circuit, the mechanical handling of goods can be carried out most efficiently. Frequent interruption of the beam indicates the possibility of congestion on the conveyor and can be made to switch over to a lower conveyor speed. Similarly, infrequent interruption can be the controlling factor to speed up the drive. In some cases the interruption of the light can be synchronized by cam contacts to coincide with some other operation of a machine, as for example, in certain forms of packing machines the photoelectric circuit is completed when the wrapper is in the process of being folded so that the contactor starter of the machine is automatically tripped if the wrapper is missing.

Fig. 17.—Photoelectric timing on a speedway track.

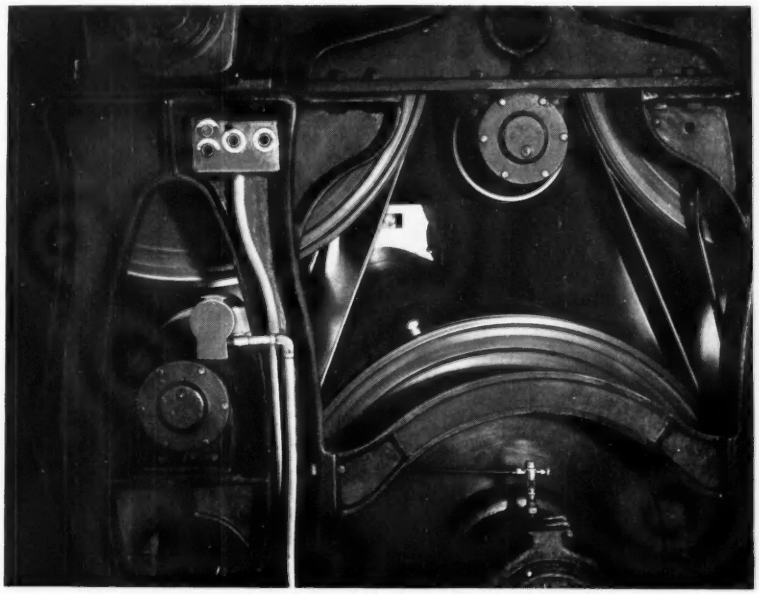


Fig. 18.—Photoelectric equipment installed on a paper machine in Bowater's Paper Mills Ltd., Gravesend, for detecting breaks in paper*.

made by a spark on a rotating graduated chart. In this case the photocell is arranged to control the grid potential of a gasfilled relay. The cut-off of the light initiates the anode discharge of the gasfilled relay which releases the charge of a large condenser through the primary of a transformer, in the secondary side of which the spark gap is included. The obvious advantage of this method of recording is that all contacts are eliminated and the inaccuracies associated with the drag of pen recorders entirely obviated.

Considerable use has been made of photoelectric controls in the paper making and printing industries, particularly in detecting breakage and securing alignment in the process of reeling. Fig. 18 shows a close-up view of the units installed at one of several points of detection at the dry end of a paper machine in Bowater's Paper Mills Ltd., at Gravesend. When a fracture occurs the high speed of the paper—1,000 feet per minute—involves a considerable delay by the extremely rapid accumulation of waste paper. As shown in the illustration, the paper normally obstructs the light from the lamp which is directed on to the moving web which is about 30 feet wide. An alarm in the form of a syren comes into action when fracture occurs and light reaches the photocell. Similar units are installed at the wet end and at

The timing of sporting events is but another simple application of the trigger circuit. As the time of cut-off in such cases is usually approaching that of one cycle of the supply, the amplifier should not be used on the A.C. supply without rectification. In the case of speedways and horse racing tracks the start of the time is made by a mechanically operated contact which excites the electromagnet of the clock movement and starts the recording, the stopping of the record, which is made by the cut-off of the light, actuating the amplifier relay. In such cases, the relay must be designed to lock in when excited, otherwise the momentary impulse is too short to pull the striking armature of the clock movement fully home. Alternatively, the clock, or stopwatch, may be dispensed with and a record

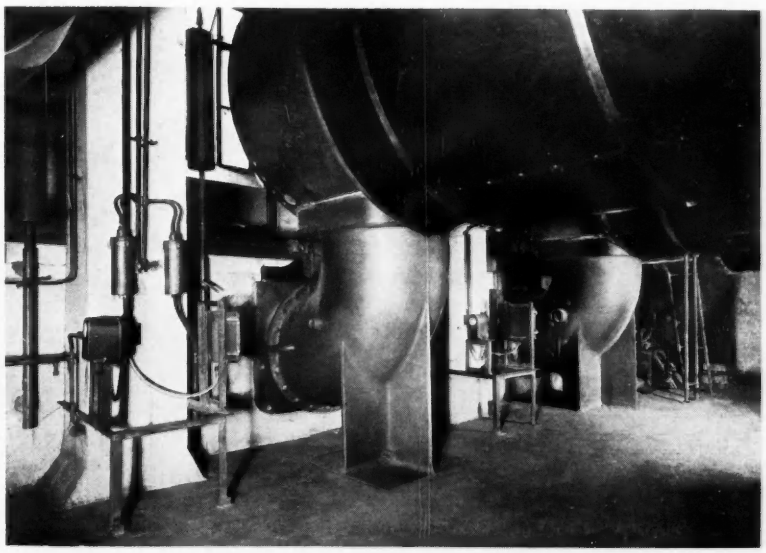


Fig. 19.—Photoelectric equipment for smoke detection in a boiler house.

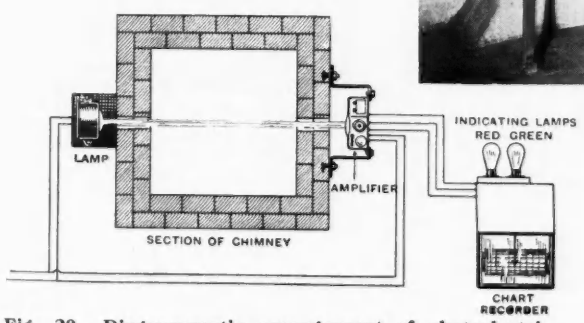


Fig. 20.—Diagrammatic arrangement of photoelectric equipment for smoke detection.

*British Patent No. 365184.

intermediate points, and the valve circuits are fed to a test panel so that the condition of valve emission is always known by milliameter readings.

Equipment of this kind is also in continuous operation at Bowater's Mersey Paper Mills Ltd., Ellesmere Port, Wirral.

The detection of smoke is an industrial use of photoelectric equipment which is of considerable practical importance. The most sensitive method of detecting solid particles in suspension is by the use of scattered radiation, but for factory chimneys where the smoke stratum is relatively dense the use of standard units and transmitted light (figs. 19 and 20) is sufficiently sensitive and meets all normal requirements. A chart record of the period during which smoke has passed can be made by a simple electromagnet actuating a pen giving a

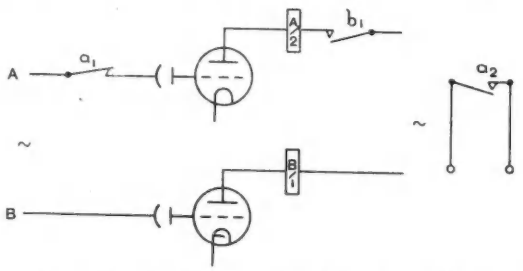


Fig. 21a.—Circuit diagram showing the application of photocells to maintain a constant level of coffee in a packing machine.

"smoke" or "no smoke" indication. No attempt is made to give quantitative indication of smoke density or make any record whose accuracy depends essentially on the constancy of the valve characteristics.

The London Electric Railways have made use of simple trigger circuits for warning lights on platforms and for escalator speed control. In the former case a space exists on curved platforms between the edge of the platform and the step of the coach. Warning lights underneath the edge of the platform are put on by the passage of the driver's cab through the light beam at the train exit end of the platform.

At stations where there are periods of light traffic it is desirable to minimize wear and tear on the mechanical portion of the escalator by keeping it at slow speed while no passengers are on it. Change to higher speed is made gradually when the passengers interrupt the light beam spanning the entrance, and a timing circuit maintains the high speed until the last passenger has completed his journey on the stairway.

Both these examples are instances where mechanical contacts would be objectionable and difficult to design.

Instances of the use of photocells for protective devices are exemplified in the case of gas or oil fired furnace control where the cell is set to receive radiation from the incandescent flame and cut off the fuel supply so as to prevent the accumulation of explosive matter if the flame for any reason becomes extinguished. Also, in conjunction with an infra-red filter on the exciting lamp, the relay contacts may form part of a closed circuit system for burglar alarm installations. The relay contacts in general would be used in conjunction with spring door and window contacts. In both these instances, the circuit of fig. 10 would be employed so that failure of valve emission would automatically bring the alarm into operation. Alternatively, a four-electrode valve with an additional relay in the auxiliary grid circuit can be used as a safeguard against valve failure.

For protective schemes of a more ambitious scale, the area spanned can be increased by successive reflection from suitably placed mirrors and the source of illumination mechanically interrupted at a specified frequency, the amplifier relay being

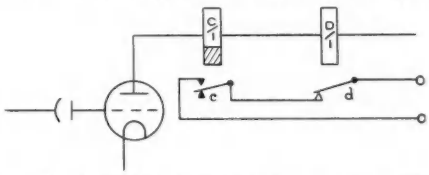


Fig. 21b.—Typical photocell circuit for controlling the billet handling plant in a rolling mill.

tuned to the same frequency. This obviates elaborate screening of the amplifier from stray light.

Two further cases in which modifications of the

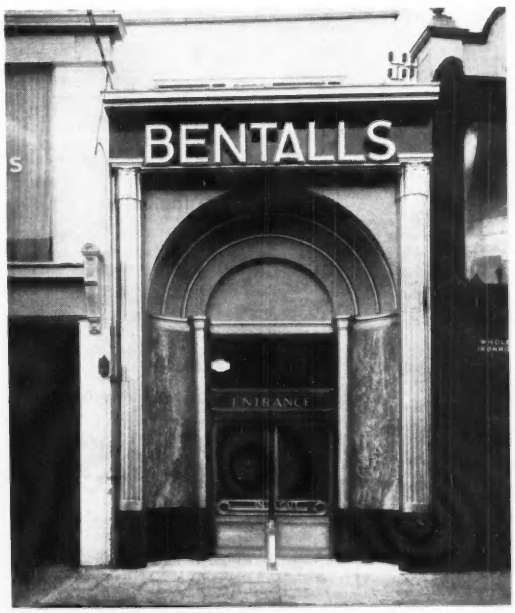


Fig. 22.—Photoelectrically controlled doors at the entrance to Bentalls Ltd., Kingston.

simple trigger circuit have proved useful may be mentioned. In the first, the photocell maintains a constant level of coffee in a packing machine.

The efficient operation of the packing process is dependent on the pressure of the coffee, and therefore the height in the hopper being kept within certain limits. This is secured by means of two rays passing through glass windows recessed into the side of the metal structure on to photocells at appropriate positions on the hopper. With the motor speed adjusted to feed at slightly too high a rate, the level of the material being assumed to be between A and B (fig. 21a), the relay contact b_1 will be closed and those of relay A in the position shown. On reaching level A the material will obscure photocell A, opening the relay contacts a_1 and closing a_2. The former contacts switch the photocell out of circuit and enable the normal anode current of the valve to lock relay $\frac{A}{2}$. The latter contact cuts out part of the field resistance of the feed motor and reduces its speed. The level in the hopper then falls slowly until photocell B becomes uncovered, when contact b_1 is released and the circuit of the upper cell at level *B* reset, the opening of a_2 inserting resistance in the field of the motor and increasing its speed and rate of feed. Incidentally, the arrangement shown at the upper level illustrates a simple way in which the external circuit controlled by the photocell can be closed permanently by the first interruption of the incident light until reset by an independent control which can be made to short circuit contact a_1 or to open momentarily the anode circuit of the valve.

The second concerns the special case in which it is required to operate the controlled circuit immediately after the passage of an object through the light beam, and to distinguish the case when light reaches the photocell after an interruption from the state when light is permanently incident on the cell. This condition arises in the case of a rolling mill where billets of metal are reduced in thickness to a required degree by repeatedly passing through the mill, the length increasing after each pass. The billets which have to be picked up from the conveyor when just clear of the mill cannot, by reason of their varying length, operate the control gear by obscuring light on to a photocell, or by the insertion of time delay device to operate subsequently to such an interruption. The tail of the billet is, however, fixed in position after each pass and can therefore be made the controlling factor. The amplifier circuit is modified to include two telephone relays in series (fig. 21b), one of the normal type and one having a heel slug to secure slow release after having once been excited. The position of the relay contacts before any interruption takes place is shown in fig. 21b. When the billet is passing, both relay contacts move to the upper position. Immediately the light is restored contacts *d* are closed but those of *c* are retained momentarily by reason of the slow release and the controlled circuit is impulsed, and in turn operates the pilot air valve which starts the lifting gear to transport the billet to another conveyor and start its tour of the rolling mill afresh.

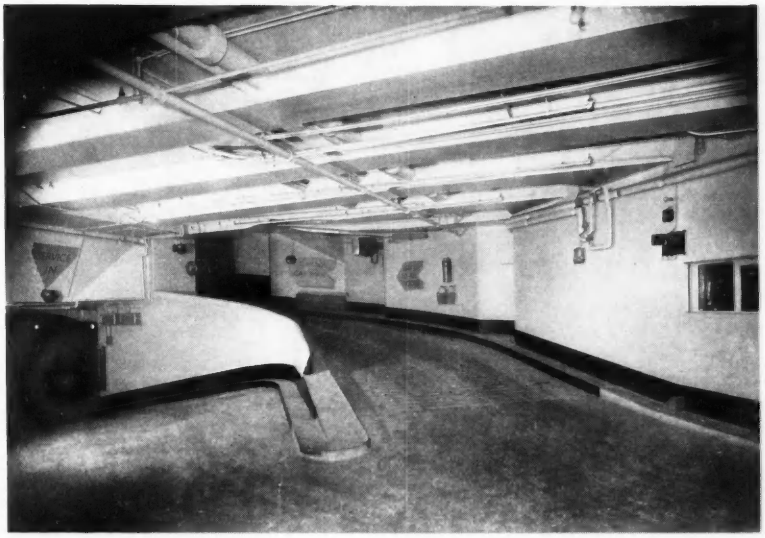
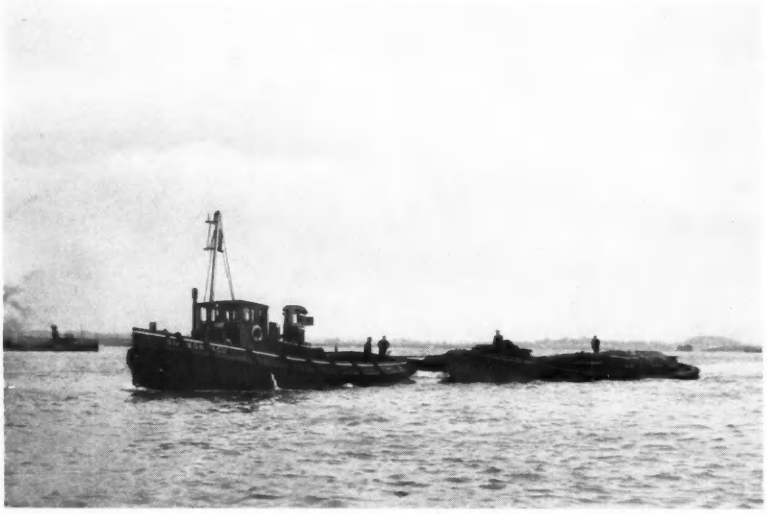


Fig. 23.—Height indicator at garage entrance of the Cumberland Hotel, London.

Other examples of practical industrial applications, of which space does not permit a detailed description, are shown in figs. 22 and 23, while the latest application, which is one of considerable interest and importance, is the photoelectric aligning method adopted on the swing span of the new Kincardine-on-Forth Bridge. A full description of the operation of this equipment is given on pages 245 to 247 of this issue.



The Diesel-Electric Tug "Sir Montagu"

By C. WALLACE SAUNDERS, M.I.Mar.E., A.M.I.C.E. A.M.I.E.E., Manager, G.E.C. Marine Department.

Fig. 1.—The Diesel-electric tug "Sir Montagu" in service on the River Thames.

FOR some months now the latest Diesel-electric tug to be built in this country, the "Sir Montagu," has been in commission on the Thames, towing barges and engaging in general river service. The "Sir Montagu" is owned by the Erith and Dartford Lighterage Co., and was built at Middlesbrough by Smiths Dock Co., Ltd., to the specification, and under the supervision of the consulting engineers, Burls Gordon and Whiteford. She is a typical Thames tug, being about 70ft. long, 16ft. beam and 8ft. maximum draught, and is engined by a 440 b.h.p. 650 r.p.m. Paxman Diesel engine direct coupled to a tandem generator set which generates power for propulsion and auxiliary purposes. The whole of the electrical propulsion and control equipment was manufactured by The General Electric Co., Ltd., and it is proposed in this article to give a brief description of the equipment installed.

The "Sir Montagu" differs notably from the three earlier Diesel-electric tugs in use in this country in that the electric propulsion and control system has been much simplified. Of the earlier tugs, one, the "Acklam Cross,"* has electric starting of the engines, using the main generators as motors; another has an arrangement whereby a generator can be taken out of, or put into circuit, without interrupting the power supply, while all three have two generating sets each coupled to a separate Diesel engine.

While there is much to be said for these extra features in certain instances, their inclusion introduces considerable complications in the control gear. The proven reliability of modern electrical machinery for marine work has, however, been sufficiently demonstrated even for the most conservatively minded marine engineer, and the need for two or more

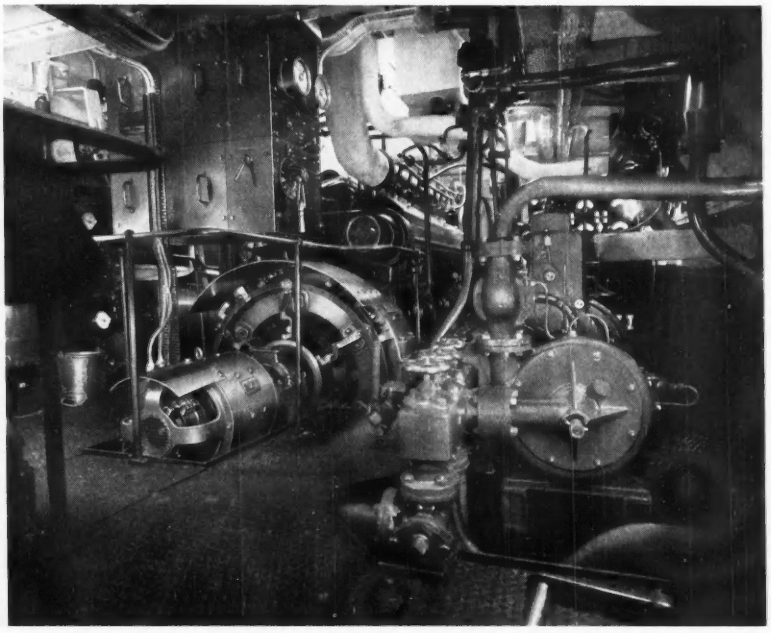


Fig. 2.—Engine room of the "Sir Montagu," showing the main 440 h.p. Diesel-engine driving the main 290 kW and auxiliary 13 kW generators in tandem.

*—G.E.C. Journal, Vol. V., No. 1, p. 55.

generators in this class of vessel, supplying a double armature propulsion motor to provide reserve power plant in case of the failure of one of the units is now largely discounted. The only instance, in fact, where two separately driven generators are of value in vessels of this class is where the tug is frequently required to proceed at an economical speed under half power.

This requirement is not demanded of the "Sir Montagu" as her primary function is the towing of barges at full power and speed, and rapid manœuvring when handling the barges at wharfs, which again demands full power. Half power running is therefore very seldom required, so that it has been possible to employ the simplest system of propulsion and control. The one main generator supplies a single armature propulsion motor, eliminating the use of switches in the main circuit which are necessary in a twin engine layout for bringing into use either one or both of the generators. In addition, a smaller number of cables is required and their arrangement simplified.

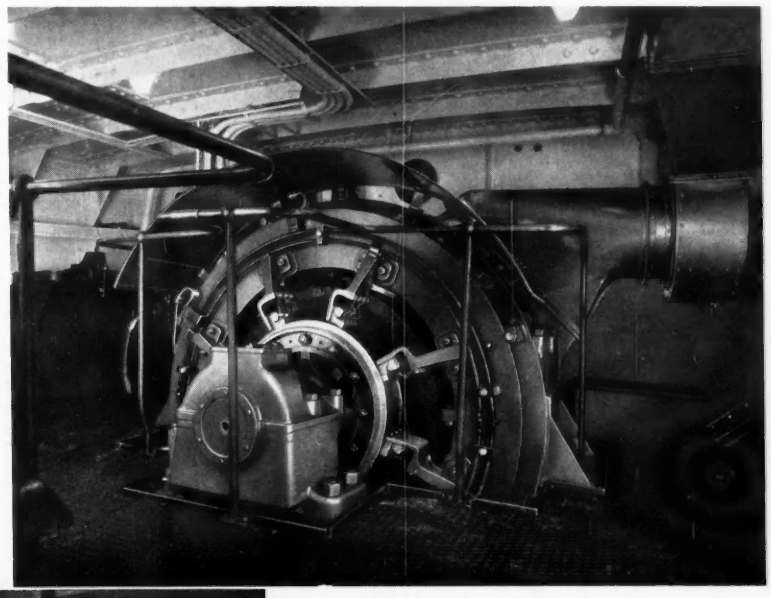


Fig. 4.—350 h.p. Propulsion motor directly coupled to the propeller shaft.

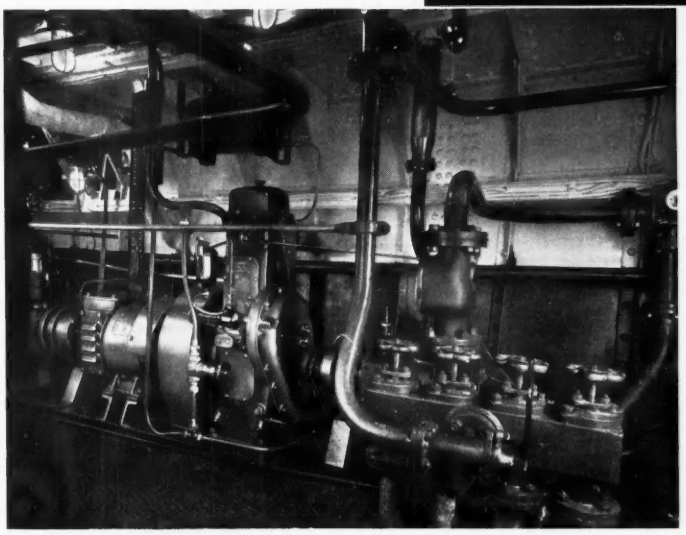


Fig. 3.—Standby Diesel engine driving 5 kW generator, air compressor and bilge pump.

PRIME MOVER.

The main Diesel engine is of the 4-stroke vertical type with eight 9½ins. bore 12ins. stroke cylinders giving a rated output of 440 b.h.p. at 650 r.p.m. Cylinder liners of the wet type, with freedom for expansion at the lower end, are fitted and the cylinder heads carry horizontal valves. A feature of this engine is the ease with which the pistons may be removed through the crankcase doors in a few minutes without in any way disturbing the cylinder heads or having to empty the water jackets.

The air starter valves are automatic in action and the engine is controlled by a single hand lever and a starting air control valve.

It will be of interest to quote the official fuel and lubricating oil consumption figures as recorded during the official tests of the engine. The fuel consumption at full load was 0.385 lb. per b.h.p. per hour, and at 10 per cent overload, 0.392 lb. per b.h.p. per hour. Lubricating oil consumption during the test run was 1.24 pints per engine hour.

MAIN AND AUXILIARY GENERATORS.

Coupled to the engine is the main 290 kW, 400/0/400 volt, 650 r.p.m. direct current generator, and in tandem with this, on an extended shaft, is an auxiliary generator having an output of 13 kW at 110 volts D.C. The auxiliary generator is compound wound and fitted with interpoles. On each magnet frame, which consists of an all-steel fabrication, are bolted the main laminated poles and solid interpoles. The main generator is provided with a few differential series turns and is connected to the propulsion motor by two 0.4 sq. in. single core cables per pole. These cables are cambric insulated, lead covered, taped, braided and compounded. The auxiliary generator is designed to supply the excitation and auxiliary load at 110 volts. It is connected to the

propeller motor and propulsion generator fields *via* the bus bars and a double pole circuit breaker on the auxiliary switchboard.

In addition, an auxiliary set is provided, consisting of a Paxman-Ricardo high speed Diesel engine developing 10/11 b.h.p. at 1,000 r.p.m. coupled to a 5 kW, 110 volt D.C. generator. At the generator end of the engine a clutch is fitted, through which an air compressor is driven; at the other end of the engine there is a bilge pump, also driven through a clutch.

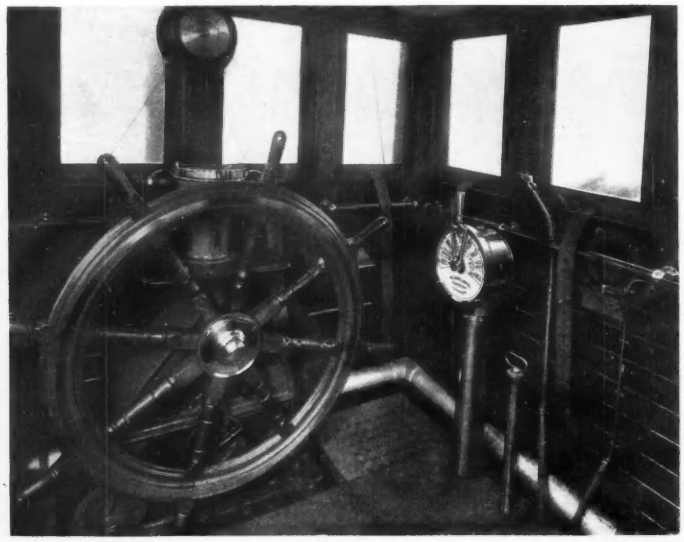


Fig. 5.—View in wheelhouse showing (on right), telegraph coupled through shafts to drum controller in engine room.

The auxiliary generator is for stand-by purposes and provides the lighting supply when the main generator is not running. It is compound wound and connected to the auxiliary switchboard but is not used for excitation.

MAIN PROPELLING MOTOR.

The propulsion motor which is directly coupled to the propeller shaft is rated at 350 shaft horse power at 120 r.p.m., 400 volts, but has a speed range of 0/120/150 r.p.m. The increase of motor revolutions from normal full speed (120 r.p.m.) to 150 r.p.m. for free running only, is obtained by opening the motor field weakening switch. This introduces a resistance into the motor field and causes the propeller speed to rise to 150 r.p.m. The motor is shunt wound and fitted with interpoles.

As in the case of the generators, a fabricated construction is employed. For ventilation of the motor, a motor-driven fan having an output of 4,000 cu. ft. of air per minute is provided, and arranged at the side of the main motor. A Michell combined thrust and journal bearing at the after end of the motor takes the propeller thrust.

All the generators and main propeller motor are protected by canopies and the windings are specially insulated for marine service.

CONTROL GEAR.

The propulsion motor is controlled on the Ward-Leonard principle, which affords smooth but rapid acceleration and instant response for manœuvring. The telegraph handle in the wheelhouse is coupled to a series of shafts through which it actuates a drum-type controller connected in the main generator field. The generator field current may thus be varied and reversed, with corresponding variations in the main motor speed and direction.

The drum controller is housed in a steel cubicle suspended over the main generator. The front of the cubicle carries a telegraph type handle (giving alternative operation of the drum controller), a centre zero ammeter which reads the propulsion current, and a propeller revolution indicator. This indicator may also be used as a voltmeter to read:

(1) Main generator voltage.
(2) Positive line to earth for leakage tests.
(3) Negative line to earth for leakage tests.

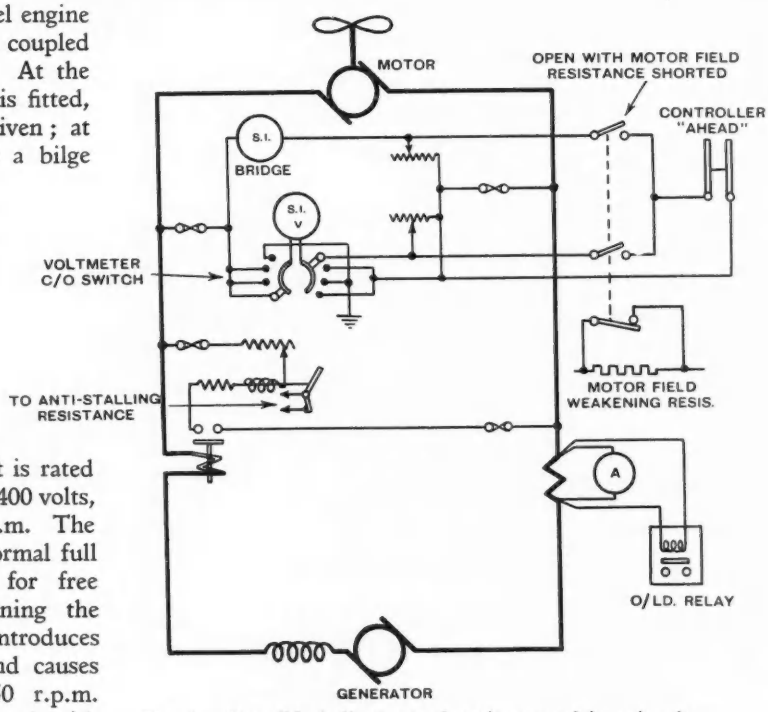


Fig. 6.—Simplified diagram of main propulsion circuit.

On the left hand side of the cubicle is mounted a lever which operates a dog clutch, coupling the controller either to the bridge or to the engine room telegraph handles.

PROTECTIVE DEVICES.

Short circuit in the fields of the propulsion machines, or in the control gear, will cause the excitation circuit breaker on the auxiliary board to trip by means of its overload coils.

Excessive current in the propulsion circuit (above the peak values occurring during manœuvring) such as might be caused by a partial motor field failure, will cause the overload relay to energize the shunt trip coil and trip the excitation breaker.

When starting, a no-volt coil prevents the breaker being closed unless the main controller is at "Stop," and the auxiliary generator up to full voltage.

In order to permit free operation of the telegraph handle without causing overload on the prime mover, a special anti-stalling gear is provided and is mounted on a panel in the control cubicle. This gear, which comprises current and voltage elements, is arranged to allow heavy peak currents to pass at low voltage, while limiting the current in the propulsion circuit at higher voltages. Thus quick response to the telegraph is obtained, while overloading or stalling the engine is entirely avoided.

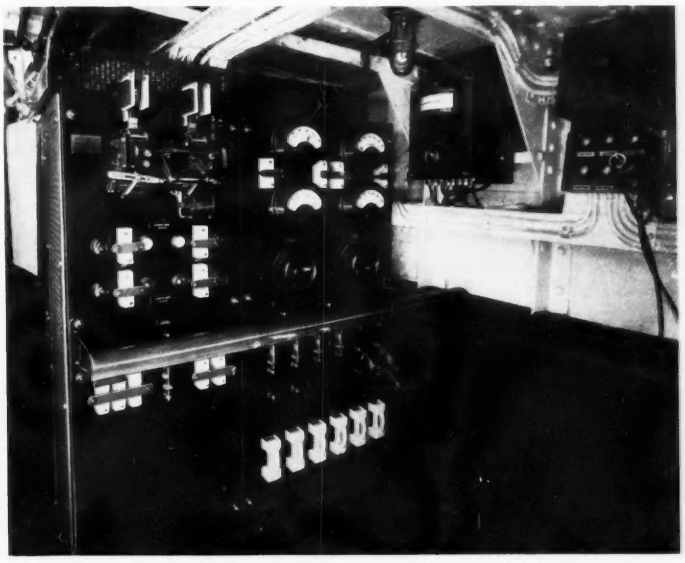


Fig. 8.—Auxiliary switchboard controlling auxiliary and standby generators, lighting and excitation circuits.

AUXILIARY SWITCHBOARD.

An auxiliary switchboard of the flat back type is installed and is situated in the starboard wing of the engine room, near the auxiliary generator set. On it are mounted switches and fuses to control the supply from the two auxiliary generators, and also to the various lighting circuits, pumps, main motor and fan and excitation. At the left hand end is mounted the double pole circuit breaker, provided with two overload coils, no-volt and shunt trip coils, the functions of which have been described above. The closing of this circuit breaker energizes the main motor field directly at full strength.

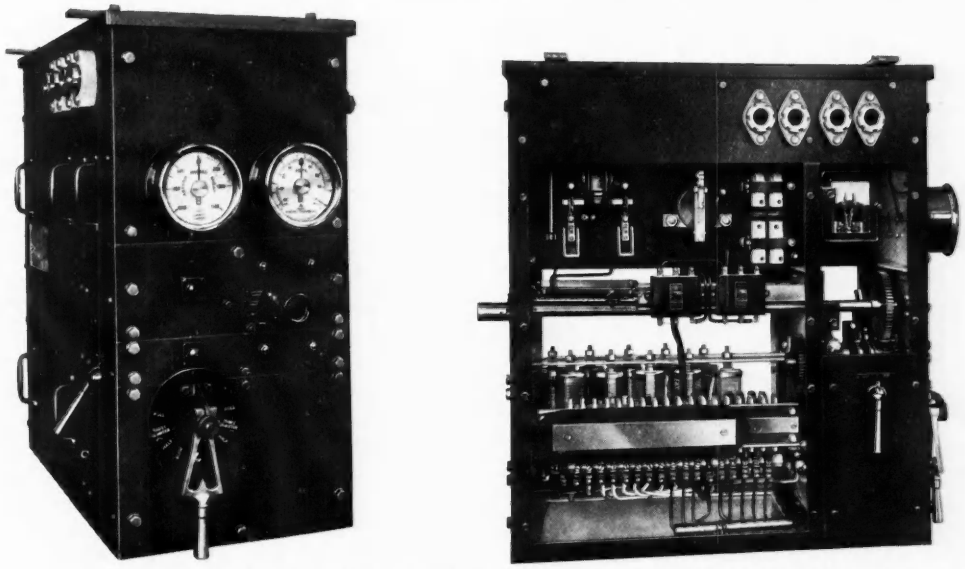


Fig. 7.—Exterior and interior views of the control cubicle in the engine room.

The Appraisement of Loudspeakers.

PART I.

By F. H. BRITTAIN,

Research Laboratories of The General Electric Co., Ltd., Wembley, England.

ALTHOUGH it is customary to think of loudspeakers only in connection with radio sets, they are in fact used for a number of purposes. This must be remembered when measuring and judging their performance, and further, it must be borne in mind that the electrical input to the loudspeaker is seldom perfect, so that it is necessary to know how these imperfections limit the performance of the loudspeaker itself.

It will be useful first to give a list of ways in which the reproduced sound may depart from the original, making no mention of whether it is due to the loudspeaker or to the associated equipment. These ways will then be discussed in greater detail, and in the case of the loudspeaker, will show first the limitations to its performance imposed by the input, and then indicate methods of measuring faults when they arise in the loudspeaker itself. Part II. of this article will be devoted to showing what are the principal limitations of the ear, and to what extent they modify the results which we should expect if the ear were perfect and would not tolerate anything but perfect fidelity.

Common imperfections of electro-acoustic systems come under the following heads, roughly in order of importance :—

(1) Frequency discrimination. That is, the reproduction of different frequencies of the same amplitude as different frequencies of different amplitudes.

(2) Harmonic distortion. That is, the production of harmonics and subharmonics not in the original.

(3) Spurious audio frequencies in the reproduction, not in the original sound, which may or may not be harmonically related to the fundamental input. What is termed "background noise" and "summation tones" come under this heading.

(4) Frequency shift. A given frequency appears as a slightly different frequency when reproduced. Not to be confused with harmonic distortion.

(5) Reduction of volume range.

(6) Transient distortion. Lack of fidelity in abrupt changes of volume or frequency.

(7) Phase distortion. Displacement of the time of arrival of one component of a wave relative to another component of the same wave.

(8) The variation of transmission time with frequency.

(9) Electro-acoustic efficiency.

(10) Power handling capacity.

(11) Constancy of performance.

In dealing with these imperfections in greater detail, we shall consider the effect that they have on the performance of loudspeakers to be used for (a) domestic entertainment, such as the reception of broadcast programmes, gramophone reproduction and television, (b) public entertainment such as talking films, etc., and (c) public address; these being the purposes for which loudspeakers are most frequently employed. There are other ways in which loudspeakers are used, but they are generally restricted in scope, and there is no need to deal with them here at any length.

FREQUENCY DISCRIMINATION.

Domestic Entertainment.

In broadcasting, the frequencies between 50 and 7,000 cycles are usually fairly well transmitted if the sound originates in a studio, but if the sound originates under less carefully controlled conditions such as "outside broadcasts" the frequency band may be much curtailed. In the case of reproduction from a gramophone record, the frequencies recorded lie between about 6,000 cycles and 200 cycles, after which there is a progressive reduction in output until about 40 cycles, below which there is usually a complete cut-off. The frequency discrimination of radio receiving apparatus is nearly always severe. On broadcast receivers, owing to the closeness of adjacent stations, it is not usually possible to receive frequencies above about 7,000 cycles, and this figure is only reached under favourable conditions. At the low frequency end the cost of equipment usually necessitates a reduction in output below about 80 cycles. The small size of the average table set makes reproduction of frequencies below this value nearly impossible, with the normal types of loudspeakers at present in use. Some of the newer sets are fitted with a device for expanding the frequency range so that any station well separated from or much stronger than its neighbours, may be received with as wide a frequency band as possible. At the present time this high

frequency band never exceeds about 10,000 cycles in the most extreme case. Fig. 1 shows the frequency discrimination of a modern radio set equipped with frequency expansion.

Public Entertainment.

The frequency range of present day talking films goes up to between 6,000 and 8,000 cycles but it is usually limited, if mechanical recorders are used, by the main resonance of the recorder and by the width of the scanning light used to record the sound. The photographic emulsion also sets a limit to the highest frequencies that can be recorded. The reproducing scanning light also gives a reduction and finally a cut-off of the highest frequencies. The low frequency end is often modified for two reasons, the inability of the loudspeaker to handle large powers

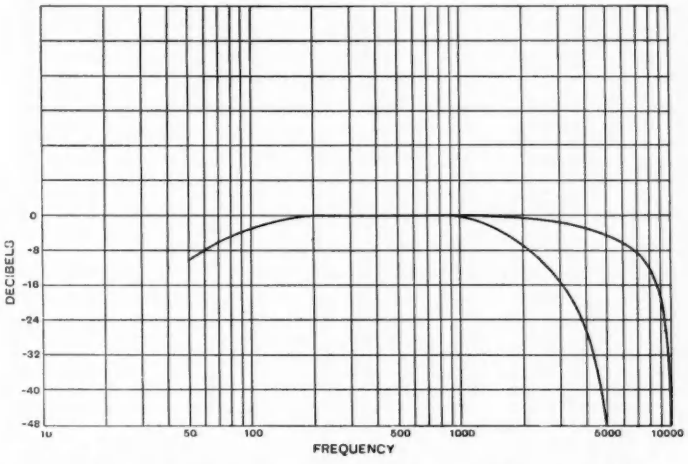


Fig. 1.—Frequency discrimination of a modern set with frequency expansion.

at these frequencies, and the fact that when a sound is reproduced at a higher volume level than the original, there appears to be an excess of bass. If speech is to be audible at good volume level all over a large auditorium, then some of the seats near the source of sound will receive a reproduced volume level which is in excess of the original in order that the level at the back of the auditorium may not be too low.

Public Address.

In dealing with public address we will confine ourselves to the reproduction of speech. For the reproduction of music, all that has been said about talking films applies here also. In the present case, the prime requirement is good articulation. Fidelity is seldom attempted owing to the fact that as the reproduced sound is vastly in excess of the original, it is quite impossible to make it sound like the original due to volume difference alone. It has been found that frequencies below about 200 cycles may be omitted with a distinct gain in articulation. It is quite common practice to reduce deliberately the high frequencies over about 6,000 cycles in order to reduce background noise in the present day carbon microphones which are generally used for public address. If the apparatus is used for the dual purpose of reproducing music as well as speech, the reduced frequency range is at once noticeable as we are now endeavouring to recreate sounds, not merely impart intelligence. It is therefore most important that the speech frequency restricting circuits should be associated with the speech microphone and should not be common properties of the rest of the circuit.

The Measurement of Frequency Discrimination in Loud Speakers.

Dealing now with the frequency response of loudspeakers themselves, we find that the early loudspeakers suffered so badly from frequency discrimination that all other failures were negligible by comparison. At that time there was no apparatus available for the measurement of frequency response, and little progress was made until the condenser microphone was introduced in America by Wente. This type of microphone can be accurately calibrated and will hold its calibration for long periods. As an example, a G.E.C. standard condenser microphone was calibrated at the National Physical Laboratory and after three years it was returned for re-calibration. The absolute sensitivity was found to have changed by less than 5 per cent at 1,000 cycles. Fig. 2 shows a photograph of this microphone. It should be noticed that the diaphragm is almost flush with the front of the microphone, thus preventing the cavity resonance which had been a serious fault with all the condenser microphones up to this time. The insulation of the microphone is an accurately ground quartz ring which is largely responsible for the permanence of calibration. With this type of instrument it became possible to measure the frequency discrimination of loudspeakers.

The Use of Acoustically Absorbing Rooms.

It was found that if the measurements were made in normal living rooms, the "standing waves" set up by the sound reflected by the walls of the room interfering with the sound coming direct from the source caused very serious irregularities in the loudspeaker response curve, and this defect could be eliminated only by measuring the loudspeaker in surroundings which did not reflect sound. This was done either by placing the loudspeaker in the open air at a height above the ground so great that the reflected wave from the ground was negligible

or by building a special room so treated that it would absorb all the sound and reflect none. A considerable amount of work has been done in America with wind screens for reducing the interference from wind

Fig. 2.—Standard G.E.C. condenser microphone.

when the measurements are made out of doors, but in this country it was decided from the first that the weather was not sufficiently reliable to allow the use of the open air. Acoustically absorbing rooms were therefore used. Fig. 3 shows the interior of such a room built at the Research Laboratories of the G.E.C. Its dimensions are 16ft. by 10ft. by 8ft., and it is rendered non-reflecting by two layers of cabots quilt, a special form of sound absorbing material particularly useful for absorbing waves of low frequency. Cabots quilt consists of eel grass between layers of brown paper, and depends for its action on the paper being compressed by the pressure wave and squeezing the grass. Over this quilt are placed seven layers of gamgee tissue, the function of which is to absorb the high frequencies which would otherwise be reflected from the surface of the brown paper. The gamgee tissue depends for its action on the damping effect of all the small cells of which it is composed. This type of damping can only be used where the thickness of the material is comparable with the wavelength of the sound to be absorbed.

The damping of this room has been found in practice to be quite satisfactory. So complete is the sound absorbtion that if an observer speaks quietly, facing the padding, at the remote end of the room, he will be inaudible at the other end. If, however, he holds a piece of cardboard up in front of him he will at once become audible by reason of the sound reflected by the card.

Positioning of the Loud Speaker.

In the early days, loudspeakers were all of the horn type, and it was necessary to decide on the relative positions to be occupied by the loudspeaker and the microphone. For convenience in amplification, it was considered desirable to place the loudspeaker as close to the microphone as possible so as to produce a large pressure, and in the case of a not too absorbent room, this arrangement also reduces the reflected wave. The closeness is limited by the fact that at low frequencies the microphone might be coupled direct to the loudspeaker *via* a column of vibrating air, and it would no longer measure the pressure component of the sound radiated. A distance of about one metre between speaker and microphone is the shortest that can be used, and even then the results will not be strictly accurate at the low frequencies. The microphone was usually located on the axis of the loudspeaker, but it was soon found that for most types of loudspeaker the response varies as the microphone is moved off the axis of the loudspeaker. This means that if it is desired to listen to the loudspeaker, the position of the listener must be stated or some average figure given. The subject will be mentioned again under "Reverberation."

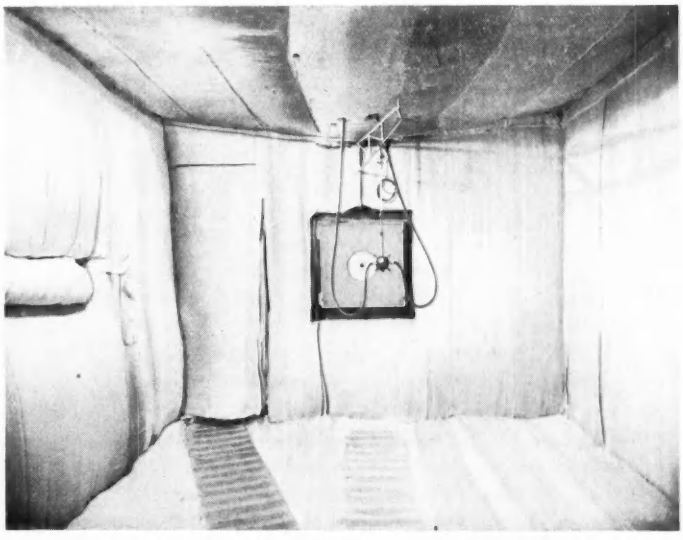


Fig. 3.—Interior of acoustically absorbing room.

When the cone type of loudspeaker made its appearance, it became necessary to provide it with a baffle in order to prevent the sound from the front of the diaphragm interfering with the sound from the back. The size and shape of the baffle controls

to a great extent the low frequency response of the loudspeaker. The ideal baffle is infinite, a close approximation may be made to this ideal case by building the loudspeaker into the wall of the absorbing room.

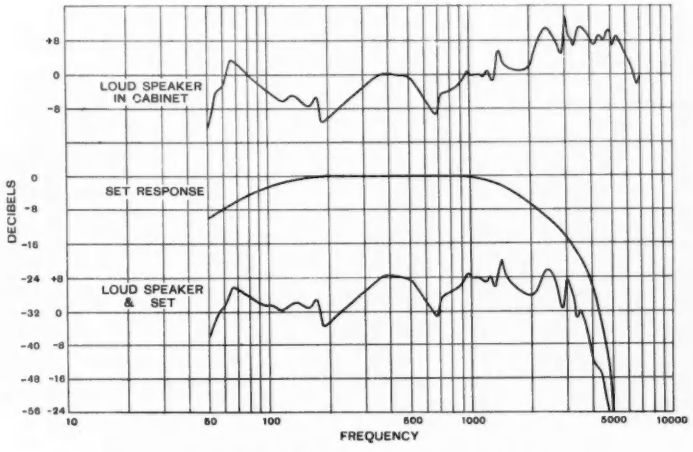


Fig. 4.—Response of loudspeaker set and overall.

Power Supply to Loud Speaker.

Some device for providing the loudspeaker with any required frequency was needed, and this took the form of the now well known heterodyne oscillator. To be correct, the sound power output should be measured against the electrical power input, but in practice it has been found sufficient to keep the current into the loudspeaker constant, and to make allowance for its impedance change. The sound pressure is measured, rather than the power, partly because the ear is a pressure-operated device, and partly it is much more convenient to measure pressure. For normal routine measurements, therefore, the sound pressure output from the loudspeaker at some specified microphone position is plotted against frequency of the electrical input. By measuring the current delivered to the loudspeaker from the radio receiver, it is possible to combine the effects of the loudspeaker and the radio receiver. Fig. 4 shows typical curves for a set and loudspeaker, separate and combined.

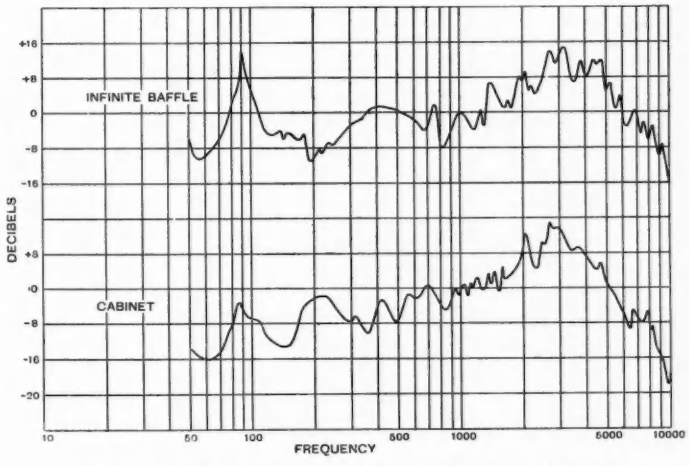


Fig. 5.—Response of loudspeaker in infinite baffle and in cabinet, measured in acoustically absorbing room.

The Effect of a Cabinet.

While this method of measuring frequency discrimination was a great step forward, it was open to several objections. In the first place the loudspeaker was placed in an infinite baffle in a totally absorbing room, a condition which is obviously quite different from any likely to be encountered in the normal use of a loudspeaker. Attempts were then made to measure the loudspeaker in the cabinet in which it would be used, and not in the infinite baffle. The normal present day construction of a cabinet is such that the sound generated by the back of the loudspeaker has free access to the surrounding air. If the cabinet is placed in the middle of the absorbing room and measurements are then taken, a response curve will be obtained which at first sight appears to give the necessary information. Fig. 5 shows such a response curve compared with the infinite baffle curve. As might be expected, the behaviour of the loudspeaker has been profoundly modified by the cabinet. Owing to the fact that these measurements are made in a room whose walls are totally absorbing, none of the sound radiated from the back of the cabinet will reach the microphone, and it is immaterial where the cabinet is placed in the room. In actual practice, however, the set is nearly always placed close to a highly reflecting wall, and sound from the back of the set will be reflected, and will influence the sound from the front of the set. The amount of the interference which this reflected sound causes will depend upon the proximity of the cabinet to the wall, the character of the wall and the surroundings, and the particular frequency which is being reproduced.

It is quite possible to build a loudspeaker cabinet in such a way that the sound generated by the back of the loudspeaker is totally enclosed, and cannot get out to the free air. There is, however, an objection to this. Either the sound generated inside the cabinet must be absorbed, or else the additional stiffness imparted to the diaphragm by the enclosed air must be considered in the design of the loudspeaker. Both of these conditions require a fairly

large cabinet, and in the first case a complicated acoustic absorber is necessary. The second case is more practicable, and an example has appeared on the market.

However, in order to counteract the added stiffness of the air enclosed in the cabinet, it is necessary to make the stiffness of the loudspeaker very small, with the result that it is usually very weak mechanically. There is the further difficulty that the pressures set up in the enclosure are greater than when free access to the outside air is permitted, with the result that there is a considerable chance that the sides of the cabinet may vibrate and upset the performance of the loudspeaker itself.

Effect of Room.

The necessity for measuring the loudspeaker in the room in which it is going to be used has been indicated owing to the large part played by the room in modifying the performance of the loudspeaker. Fig. 6 shows the response of a loudspeaker in a cabinet in the absorbing room, and also in a reverberant room. Not only has the bass response been altered by the presence of the reflected wave from the back of the cabinet, but owing to the fact that a steady tone was used, sound waves reflected by the walls of the room have interacted with each other and produced the phenomenon known as standing waves, with the result that the response curve, which was fairly smooth, is now very serrated. This is due to the fact that the microphone may be situated in such a position that the resultant sound pressure acting on it is abnormally large or small at that particular frequency.

Various attempts have been made to reduce the effects of the room on the measured response curve. Such methods as swinging or rotating the microphone in order to average up the effects of the standing wave pattern have been suggested, but as the average listener is neither rotated nor swung, these methods cannot claim to measure the response under the normal conditions under which he listens. A better method, at least as far as the high frequencies are concerned, is to apply to the loudspeaker not a steady frequency, but one which varies rhythmically about a mean frequency. This successfully breaks up the standing wave pattern and allows a smooth curve to be obtained. Such a varying frequency is known as a warble tone. It is only possible to use a warble tone on the assumption that variations in the performance of the loudspeaker do not take place over such narrow frequency bands as those produced by the room resonances, standing waves, etc. At low frequencies this is not true, and it is therefore not justifiable to use a warble method to smooth out the response in this region.

The only methods which can be used to smooth out the low frequency response consist in moving either the microphone or the loudspeaker or both. They may be moved continuously, or they may be placed in a number of fixed positions and the results averaged. There are, however, other factors which modify the performance of the loudspeaker when measured in a reverberant room. The proportion of sound reflected at any particular frequency will increase the total sound level in the room above that level which would have existed in the absence of any reflected waves. In most rooms, the amount of reflected sound varies considerably with frequency, and hence the response curve is augmented by

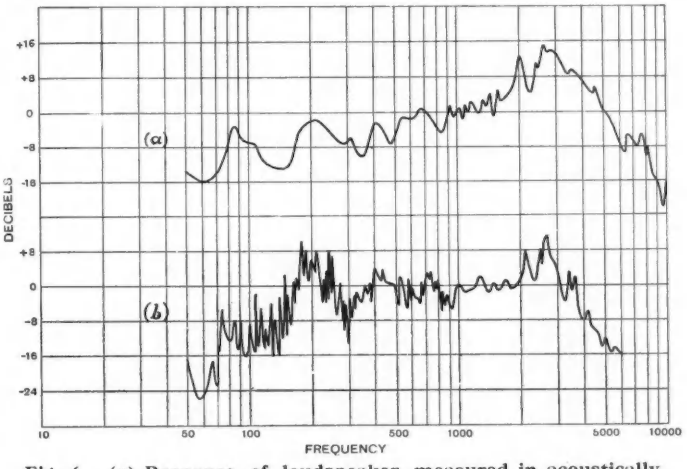


Fig. 6.—(a) Response of loudspeaker measured in acoustically absorbing room, (b) response of loudspeaker measured in reverberant room (smoothed by warble method).

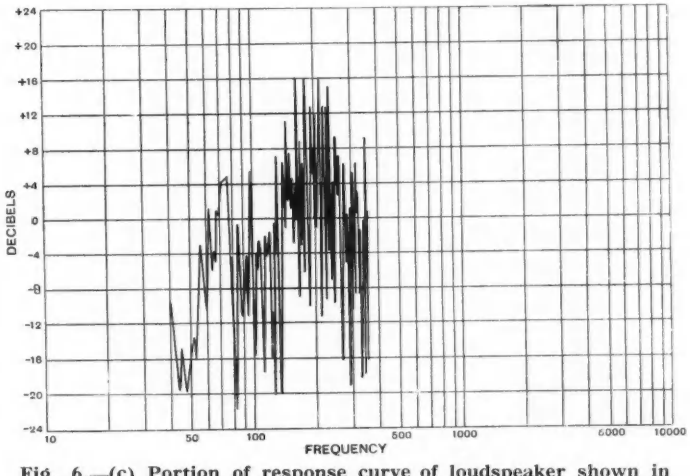


Fig. 6.—(c) Portion of response curve of loudspeaker shown in (b), measured without warble in reverberant room.

different frequencies. Most cone type loudspeakers radiate their highest frequencies in a narrow beam, and their lowest frequencies spherically, and therefore if measurements are made in such rooms on the axis of the loudspeaker, a considerable increase of low frequencies will be recorded but only a small increase of high frequencies. This is due to the fact that practically the whole of the output of the loudspeaker is directed at the microphone at high frequencies, while no radiations in other directions reach the microphone after one or more reflections. Further, alterations to the frequency response will occur if any part of the room such as windows, floor, doors, etc., can vibrate and absorb energy at one particular frequency.

From the foregoing, it will be seen that it is necessary to specify all the properties of the room together with the positions occupied by the loudspeaker and the microphone, as well as the method used to smooth the resulting curve. This is largely due to the fact that in music and speech we do not listen to pure tones, with the result that we do not notice the standing wave pattern in a room. Objective methods of estimating frequency discrimination will be described under the heading "Audition" in Part II of this article, as will also the effects which frequency discrimination and the surroundings of the listener have on the various types of sound reproduced.

At the present time it is most satisfactory, for design purposes at any rate, to measure frequency response in an absorbing room. This does at least measure only the loudspeaker when operating under those specified conditions. Whether the infinite baffle or the cabinet is to be used is open to argument. It depends largely on how far the design has progressed. In the early stages, the infinite baffle is to be preferred in order that the loudspeaker being developed may be compared with previous designs, later, it should be fitted to the cabinet in which it is going to be used. It is also very helpful to supplement this information with the mean curve of the loudspeaker in several positions in a reverberant room.

HARMONIC DISTORTION.

What follows in this section applies to all three types of usage, namely, domestic entertainment, public entertainment and public address. Harmonic distortion may occur either in the transmission system or in the loudspeaker itself. In broadcast transmissions it is largely controlled by the care with which well designed equipment is used. If the transmission or recording is made under well known conditions, in the studio for instance, the harmonic distortion may be kept at a satisfactorily low level; but if the conditions are not accurately known or if the equipment has to be reduced in size for portability, the harmonic content may reach very high levels due to some part of the equipment being grossly overloaded. At the receiving end it is again a function of the reproduced volume level for any particular equipment. Harmonic distortion is frequently very noticeable in public address equipment where it is necessary to produce a large volume of sound from a portable equipment.

For our present purposes we will divide harmonic distortion into two classes, the only difference between them being that of magnitude. We will define the first case as one in which the harmonic content is so great that it sounds like an added noise and is only just tolerable. The second case may be defined as having a sufficiently large harmonic content to "colour" or alter the quality of an otherwise pure tone. It need not be objectionable. The reason for splitting harmonic distortion into two classes arises from the fact that there is a wide variation between the permissible harmonic content for perceptibility in an otherwise ideal system, and the "just tolerable" amount which limits the maximum power which can be obtained usefully from any particular apparatus under commercial conditions.

The first type of harmonic distortion has been measured in electrical circuits by a number of means. For instance, a selective filter may be inserted between the microphone amplifier and the measuring instrument. If this method is employed, it is necessary to provide one filter for each harmonic of any given fundamental frequency. It can be used satisfactorily only on power lines where there is only one frequency of fundamental. It is very ungainly where a large number of frequencies has to be considered. Both the dynamometer and bridge methods may be employed and are capable of giving satisfactory results, but they are very tedious. A harmonic analyser working on the heterodyne principle is by far the most satisfactory, and in the second case of the less severe harmonic distortion, this is the only method which can be used.

The second type of harmonic distortion is very much more difficult to measure, due to the much smaller quantities of harmonic present, but with good equipment it is quite possible to measure harmonics too small to be audible when the loudspeaker and microphone are situated at a distance of about 6 feet in free air.

Both types of harmonic distortion can be measured in the electrical input to the loudspeaker, but the measurement of acoustic harmonic content is even more difficult than the measurement of frequency response. It is almost essential that the measurements be carried out in a non-reflecting room in order to get over the difficulties of standing waves and the effects of a reverberant room, as the methods of smoothing out room errors usually employed would be very difficult to use with an harmonic analyser. Fig. 7 shows a three dimensional model

of the harmonic content of a normal domestic loudspeaker. It gives some idea of the complexity of the results which, whilst being accurate, measurements under specified conditions are very difficult to interpret. The possibility of finding suitable factors for the two kinds of distortion, together with their subjective interpretation will be discussed under "Audition" in Part II. of this article.

SPURIOUS NOISE.

In domestic entertainment the introduction of spurious audio frequencies and noise at the broadcast transmitter is largely dependent on the position in which the microphone may be placed in the case of air-borne sounds. If the sound has its origin at some considerable distance from the microphone, small local noises may be rendered unduly prominent, also the background noise of the amplifiers and microphone may be troublesome. If the sound originates at a great distance from the radio transmitter, there is the possibility of cross talk or interference in the land line or radio link between the microphone and the broadcast transmitter. Cross modulation products, in some respects similar to harmonics, are added at all stages of the system, but in the transmitter considerable trouble is usually taken to keep them at a low value. Spurious audio frequencies are introduced by the receiver in a number of ways. If it operates from the mains, the smoothing may not be adequate, and there may be a residual audio frequency in the smoothed D.C. used for operating the receiver proper. The mains equipment may not be securely fixed, with the result that it vibrates and emits a buzz. The demodulator may not be perfect and produce spurious noise, cross modulation and harmonics. Various components may overload and add to the general noise which, as far as the receiver is concerned, is usually a function of the modulation depth and the reproduced volume level.

By far the most serious source of noise when listening to distant stations is that caused by the surrounding ether with its electrical disturbances and the background noise of the set (Schrott effect and thermal agitation in conductors) which is nearly always the limiting factor in distant reception. There may also be considerable interference from neighbouring transmitters and local apparatus. In all cases, the noise is increased by increasing the band of frequencies transmitted. In the case of reproduction from a record, the noise generated by the surface of a record is usually the most serious. It is accentuated by the fact that it is independent of the depth of recording, and therefore shows up most in the quiet passage.

Noise in Talking Films.

The noise introduced in the recording operation of talking films is similar to that experienced in broadcast transmission. The photocell used for the reproduction of talking films generates internal noise when the illumination is high. A photographic image is, except in colour pictures, composed of discrete particles of metallic silver, and when the film is passed between the scanning light and the photocell, this discontinuity becomes noticeable. To overcome these defects, both of which are dependent on the quantity of light reaching the cell, "silent background" recording has been introduced, and is so successful that there is now no noise during the quiet passages of a talking film. This method consists in reducing the light reaching the photocell in inverse proportion to the depth of modulation on the film.

Noise in Public Address Systems.

In the case of public address, the listener is generally in noisy surroundings with the result that spurious noise in the reproduced sound is not nearly so noticeable.

Noise Produced by the Loud Speaker.

The loudspeaker may introduce noise in a number of ways. It may have a mechanical fault, such as the vibrating portion fouling some other body and giving rise to a buzz, or parts of the moving system may move relatively to each other with the same effect.

There is, however, a further important source of noise due to the loudspeaker, this is the production of "sum and difference" tones. These difference

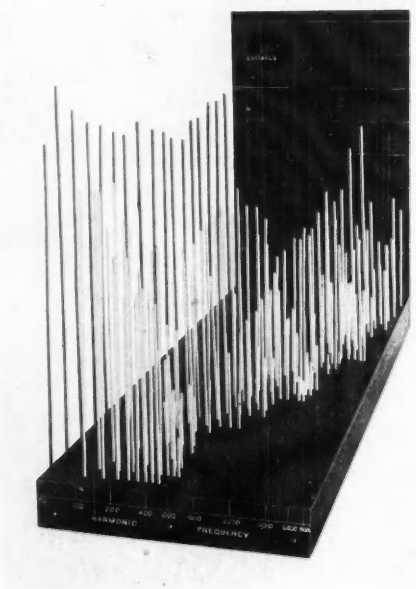


Fig. 7.—Three dimensional model showing harmonic content of typical loudspeaker.

tones are due to the fact that when two or more frequencies are applied to the loudspeaker at once, cross modulation may set in. Little work has yet been done on them, and there are the same difficulties in appraising the results as there are in determining the harmonics of a complicated sound.

The measurement of noise is best done with a harmonic analyser, due to the fact that it is usually desirable to know the frequencies of the various components of the noise, if it is desired to attempt any weighting of its "unpleasantness." Measurements can best be made in free space conditions with a steady input. The appraisement of noise is dealt with under "Audition" in Part II. of this article.

FREQUENCY SHIFT.

Frequency shift is chiefly troublesome when reproduction is made from records, including steel wire, sound on film, sound on disc, etc. It usually takes the form of a fluctuation of an otherwise steady frequency as it is quite a simple matter to correct any constant frequency shift.

Measurement of frequency shift may be conveniently made by taking an oscillogram of the original and the reproduced frequencies and comparing the number of complete cycles per unit of time. Measurements should be made over an extended period of time in order to determine whether there is any cyclic variation.

REDUCTION OF VOLUME RANGE.

In the case of domestic entertainment, a reduction of the volume range transmitted has to be made at present, due to the fact that if the equipment is so set up that it does not overload at maximum volume level, the soft passages will be masked by the background of the microphone, amplifiers, etc. In the case of reproduction from a gramophone record, the presence of needle scratch calls for a greater reduction in volume range than is necessary with direct microphone pickup.

The volume range of talking films is similar to that obtainable from a nearby radio transmitter, as owing to the use of "silent background" recording, the reproducing process can be made to add a negligible amount of noise.

In the case of public address, the volume range is not usually of interest since the system is used only for imparting information. Devices are frequently incorporated in the amplifier, so that the output is held almost constant even though there may be a large change in the input to the microphone (such as the change in position of an orator relative to the microphone).

The measurement of volume range consists in measuring the overall noise level, and also the maximum level at which overloading becomes serious. This gives the maximum permissible input variation, and by comparing it with the original, it is possible to determine the reduction necessary. Owing to the fact that it is necessary to measure the noise in the loudspeaker output and include all sources of noise, such as those associated with distant radio reception, it is clear that the volume reduction which would have to be made due to the broadcast transmitter alone is not sufficient. A small amount of noise will be added even if the listener is very close to the broadcast transmitting station. If the listener is at a great distance from the broadcasting station, then there will be a very substantial increase in noise with a consequent reduction of permissible volume range. Therefore, it is impossible to broadcast with a fixed volume range which is satisfactory for all listeners unless the volume range is considerably reduced at the transmitter and expanded at the receiver. This scheme has been shown to be quite workable, but has not yet come into general use with the broadcast authorities, with the result that receivers cannot be built to expand the volume accurately if, as at present, the volume at the transmitting station is controlled by hand at the discretion of the operator.

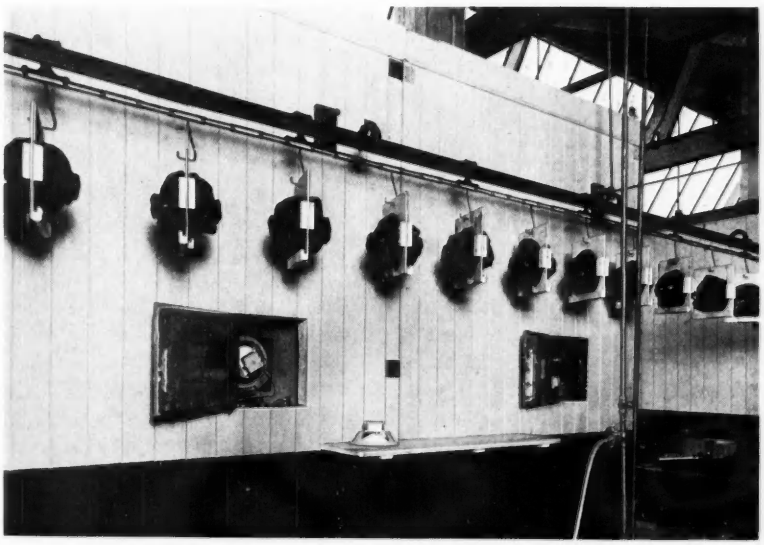


Fig. 8.—Loudspeaker test cabins at the G.E.C. Telephone Works, Coventry, showing the hatches in which every loudspeaker is tested prior to mounting in a receiver.

TRANSIENT DISTORTION.

The measurements described above are steady state measure-

ments, that is they record, strictly speaking, only the response to a steady note such as a violin steadily bowed or a vowel in speech. In the consonants of speech, the tap of a drum, or the note from a piano hammer, the sound pressure varies at a continuously changing rate to which the word frequency cannot be applied. Electrical and acoustical systems can faithfully reproduce such wave shapes only if they have no natural frequencies at all ; are aperiodic in fact. But in this case acoustic systems at any rate are quite inefficient. Hence, it becomes necessary to study the behaviour of resonant systems under conditions of suddenly applied impulses of sound under what are commonly called "transient" conditions and it is found that these resonant systems fail in two principal ways. The sudden sounds can be treated as if they were composed of extremely low frequencies, or more usually both. The resonant systems distort them partly by failing to reproduce sufficient of top and bottom components, so that for example a hand clap becomes a thud ; partly because the resonant portion starts up with a mixture of its own note and the one applied, and then finishes with its own note dying down slowly, so that a loudspeaker or a listening room with too marked a resonance may sound boomy.

The study of this question which is receiving increasing attention is difficult, particularly when the whole system is a combination of many resonances.

PHASE DISTORTION.

Phase distortion may occur anywhere in the reproducing system, particularly in any system having pronounced resonances. In loudspeakers, owing to the fact that the diaphragm "breaks up" at the higher frequencies (*i.e.*, fails to move as a whole), sounds are radiated with all sorts of phase relations to the original. Further, the phase distortion will frequently be found to change with the angle relative to the axis of the loudspeaker at which the sound is radiated. A resonance in the high frequency response of a loudspeaker will not necessarily show any phase change in the way that a low frequency resonance nearly always does. Owing to the fact that a low frequency resonance is nearly always accompanied by phase reversal, it is not possible to use more than one loudspeaker for bass reproduction unless special precautions are taken to keep the phase shift of all the loudspeakers constant. Phase distortion unaccompanied by any other phenomenon is not easily detected, but in extreme cases it shows up as a variation of transmission time with frequency.

VARIATION OF TRANSMISSION TIME WITH FREQUENCY.

This phenomenon is usually only noticeable on long underground lines, and most frequently takes the form of sounds such as a sharp click sounding like a tweet as a result of the higher frequencies arriving after the lower components. The trouble is present to a considerable extent on the lines now used for connecting broadcast transmitters in various parts of the country to a common source. Land lines are not generally used in connection with talking films, but in public address if the speech is relayed to several remote halls, this variation of transmission time with frequency may become very serious.

Fig. 9.—Interior view of the loudspeaker test cabin, showing the standard models which are installed for comparison with the production model.

ELECTRO-ACOUSTICAL EFFICIENCY.

The electro-acoustical efficiency of a loudspeaker is best defined for the present purposes as the ratio of the acoustic power in the room in which the loudspeaker is to be operated to the electrical power in the optimum resistive load for the output valve in use. A suitable impedance matching transformer has to be incorporated in most cases between the valve and the loudspeaker, and the losses of this device must be included with those of the loudspeaker, since it cannot be used without it. The present day loudspeaker is relatively inductive, and although no power is consumed by the inductance, its presence imposes serious restrictions on the associated output valve. The efficiency of the cone loudspeaker is not improved by the fact that the sound radiated from the back of the cone is nearly always wasted, and sometimes actually reduces that coming from the front of the cone. This is partly due to the small effective size of the cabinet in which

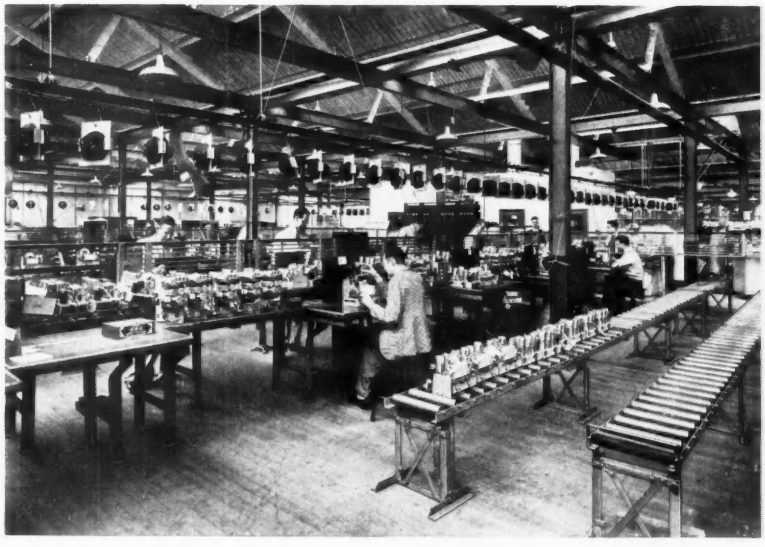


Fig. 10.—A conveyor transporting the tested loudspeakers to the assembly benches.

the loudspeaker is fitted, and partly due to reflected sound from the walls behind the cabinet.

Measurement.

Although it is obviously desirable to measure the sound output of the loudspeaker under normal surroundings, this can be done only by avoiding the use of steady tones, otherwise free space methods must be adopted as in the measurement of frequency response. In carrying out these free space measurements, it is necessary to measure the polar radiation on a hemisphere on one side of the loudspeaker in order to determine the total acoustic power. Attempts to measure the total power output from a loudspeaker in a cabinet in a totally reflecting room have been made, and if we are not concerned with the variation of output with frequency, the results are very useful. For normal comparison purposes, it is not necessary to carry out these measurements as most of the necessary information may be obtained by measuring the pressure at some point (400 cycles) on the frequency response curve, and then comparing various curves with regard to their 400 cycle levels.

Method of Improving Electro-acoustical Efficiency.

All loudspeakers suffer at one point or another of their frequency range from the fact that it is not possible to make the mass reactance of their diaphragms and other moving parts equal to their stiffness reactance at all frequencies. (The only alternative to this would be to make the mass of the moving parts infinitely small.) Light diaphragms of moulded paper have helped to improve matters, but this process cannot be carried very far without sacrificing the power handling capacity of the diaphragm. The cone type diaphragm does balance the mass and stiffness reactance at some frequencies, but it leaves large portions of the frequency response unbalanced. Also, different parts of the diaphragm may radiate out of phase and so neutralize each other. Now that diaphragms may be moulded in paper to almost any shape, it seems likely that a new type of moving coil diaphragm will be evolved having a very greatly improved frequency response and efficiency. This diaphragm will have a stiffness reactance rising with frequency in such a way that it will balance the combined mass reactance of the operating coil and the moving parts of the diaphragm.

There will still be losses due to hysteresis in the bending set up by the material, and that might well be the next step in considering the ways in which the efficiency could be still further increased. The question of the polarizing of the loudspeaker by means of either a permanent magnet, electro-magnet or in the case of electrostatic loudspeakers, the necessary electrostatic field, has been deliberately left till the last. The intensity of this field governs the efficiency of the loudspeaker, and while it may consume no power, its intensity is usually determined by the cost of the polarizing unit, and it is necessary, when comparing loudspeakers, that some allowance should be made for their relative polarizing energies.

POWER HANDLING CAPACITY.

The assessment of the power handling capacity of a loudspeaker is open to all the difficulties of assessing the power handling capacity of other parts of the system. It is very difficult to determine the precise point at which it is impossible to obtain any further increase in output without introducing excessive distortion, bearing in mind the conditions under which the loudspeaker is going to be used. A loudspeaker would probably have two totally different maximum power outputs if it were sometimes used for very high quality reproduction, and at other times for public address. Definite limits to the power handling capacity are set by the electrical and mechanical design, but at the power level at which these fail, the quality of the loudspeaker may be so bad that it is doubtful whether the limit of power handling capacity has not been passed already. Like machines, it is very desirable to have a short

time overload factor, which is considerably higher than the factor for continuous overload, but in the case of loudspeakers, it is very difficult to specify this point.

CONSTANCY OF PERFORMANCE.

Constancy of performance of a loudspeaker is not usually a very troublesome item. Not because the loudspeaker is free from variations, but due to the fact that unless we have a similar loudspeaker for comparison purposes, we shall be unable to detect quite large changes in performance. These changes may of course take any of the known ways of failure of a loudspeaker. In actual practice, they nearly always show up as mechanical failures such as the moving system rubbing on some stationary part due to lack of alignment or some such cause. Alternatively, some part of the moving system may become partly detached and buzz when used at quite normal volumes. Such failures are quite easily detected; the more obscure types are those in which change in frequency response due to water absorbed by the cone. These failures are much more difficult to detect, but they scarcely warrant the term failure.

This completes the investigation of common imperfections in electro-acoustic systems. Methods of measuring these failures have been indicated, but no system of appraising the results in the light of listening experience has been suggested. This will be done in the second section dealing with the general term "Audition."

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[To be continued.]

Lighting for Children's Playgrounds.

The danger of children playing in the road, both to themselves and motorists, has been engaging the attention of the Ministry of Transport for some time, and the provision of well illuminated playgrounds and open spaces has helped considerably towards reducing the number of accidents.

The accompanying illustration shows an example of a playground where children can play during the dark evenings. It is the "Children's Playground," Bartholomew Square, London, where an installation of 400 watt "Osira" electric discharge lamps has recently been put into operation by the Metropolitan Borough of Finsbury.

Electrification of the Lun Chong Cotton Mill

(The China Printing and Finishing Co., Ltd., Shanghai).

By N. G. BEALE,
General Manager of The General Electric Co. of China Ltd.

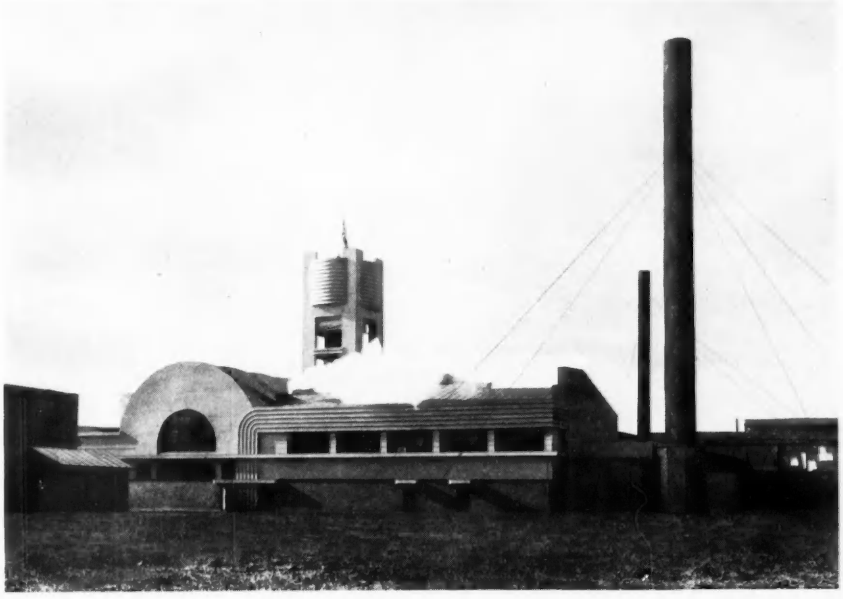


Fig. 1.—The power station of the Lun Chong Cotton Mill, China.

ONE of the largest textile undertakings in the Far East is The China Printing and Finishing Co., Ltd. This company has been established in China for a number of years, possessing several extensive factories and carrying on an important business as bleachers, dyers, printers and finishers of cotton piece goods. A further large factory has recently been added to the existing group for the manufacture of grey cotton cloth, so that the company now produces finished goods in the form of bleached, dyed and printed fabrics from the raw cotton. The finished goods are marketed throughout China by the company's selling organization which is directed from its Head Office in Shanghai.

The new factory comprises a cotton spinning and weaving mill known as the Lun Chong Cotton Mill, and is situated on the Pootung bank of the Whangpoo River at a point opposite the International Settlement at Shanghai. The total area of the new mill is approximately 75,000 sq. yards. It employs over 2,000 people, mostly Chinese, and in it are installed approximately 1,150 looms and 50,000 spindles.

The building itself and the equipment installed represent the very latest in modern practice. The comprehensive contract for the electrification of the mill, involving a complete power station with boiler plant, water filtration plant, turbo-alternators and switchgear, together with motors totalling 214 in number and 2,500 h.p. in capacity, control gear, distribution boards, cables, wiring, electric light fittings and lamps, was awarded to The General Electric Co. of China Ltd.

A brief description of the new mill and the processes involved in the production of grey cotton cloth, with particular reference to the electrical plant, is given in the following article.

POWER STATION EQUIPMENT.

The power station, fig. 1, is a reinforced concrete structure of unusual design, the architects being Davies Brooke & Gran of Shanghai. It is situated approximately 400 yards from the river bank, with plenty of space for future extensions, if required. The location of the power station with respect to the mills is such that the voltage drop along the distribution lines and the length of steam piping required for conducting heating steam to the slashing and sizing departments, are reduced to a minimum.

BOILER PLANT.

The boiler plant comprises three Babcock & Wilcox water tube boilers, each provided with two 42in. dia. steam and water drums and having a heating surface of 3,580 sq. ft. Each boiler is capable of producing 15,000 lbs. of steam per hour, as a normal load, at a pressure of 275 lbs. per sq. in.

Integral type superheaters are installed to raise the temperature of the steam to 650 deg. F. at the superheater outlet. Mechanical chain grate stokers, having a grate area of 98 sq. ft. and provided with unit driving gear and operating motor, are installed with each boiler.

A cast iron vertical tube economiser with scrapers, driving gear and motor is provided; also a motor driven induced draught fan with the necessary dampers. The driving motor is rated at 45 h.p., 360 r.p.m., and is of the pipe ventilated squirrel cage type, controlled by an oil immersed star-delta starter.

Two vertical direct-acting boiler feed pumps, each capable of feeding two boilers are installed. The exhaust steam from these pumps is taken through a coil in the hotwell so that the heat in the steam may be utilized for raising the temperature of the boiler feed water.

In order to provide heating and process steam for the mill, which is required at a pressure of 60-80 lbs. per sq. in. and a temperature not exceeding 400 deg. F., a pressure reducing valve and a desuperheater are installed. As the heating steam is only required for two or three months in the year, it was not considered advisable to extract this from the turbine. The condensed steam from the heating system is collected and pumped back to the hotwell. This condensate pump is driven by a 5 h.p. motor controlled by a contactor starter operated by a float switch. For the make-up boiler feed, water from the Whangpoo River, which contains a considerable quantity of mud in suspension, is taken from the condenser cooling water system, and delivered to a gravity settling tank. Thence it is pumped through pressure type filters to a Lassen-Hjort water softener and then delivered to the hotwell tank. Dulpicate motor driven pumps and filters are installed, each having a capacity of 400 gallons per hour, and are controlled by a float switch operating contactor starters.

An alternative supply of make-up water is available from an overhead tank, supplied from a deep well. The water from the deep well is raised by compressed air, two air compressors driven by 10 h.p. motors being employed for this purpose.

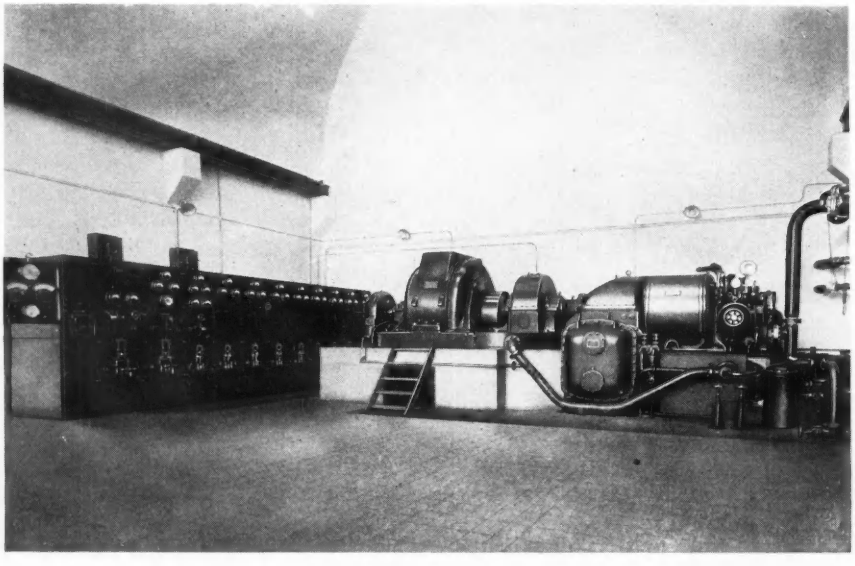


Fig. 2.—2,000 kW, 380 volt Turbo-alternator which runs at a speed of 6,000/1,000 r.p.m., and main 380 volt switchboard installed in the power station.

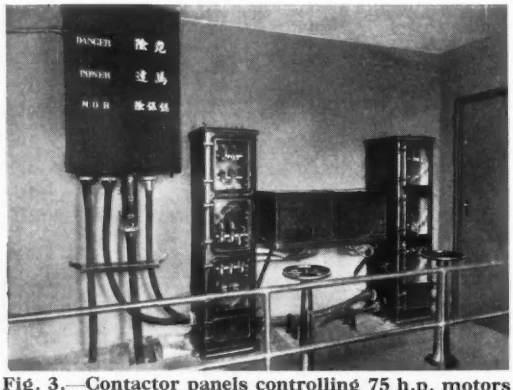


Fig. 3.—Contactor panels controlling 75 h.p. motors driving condenser cooling water pumps. On the left is seen the pump house distribution board.

POWER PLANT.

The power station is equipped with two 380 volt, 3 phase, 50 cycle turbo-alternators, one of 2,000 kW

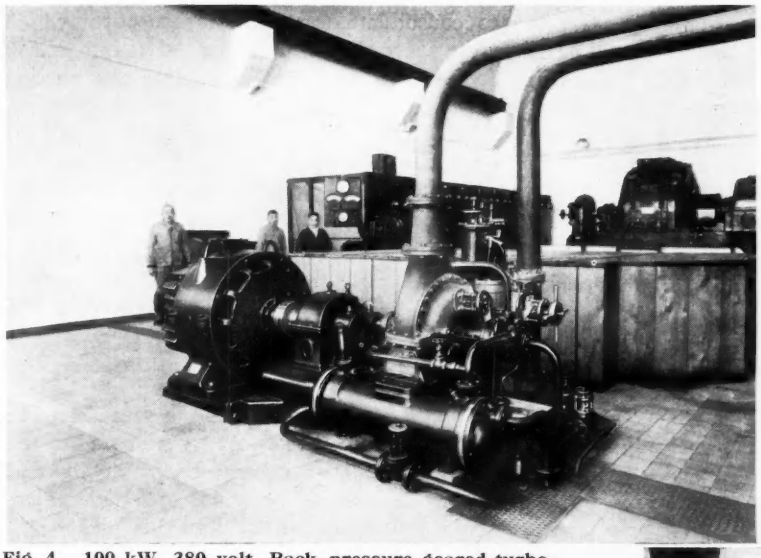


Fig. 4.—100 kW, 380 volt, Back pressure geared turbo-alternator, which runs at a speed of 7,000/1,500 r.p.m., and is used when the main set is shut down.

capacity (2,500 kVA at 0.8 P.F.) and the other of 100 kW (125 kVA at 0.8 P.F.), provision being made for two further 2,000 kW sets, one of which is at present in course of construction at Witton Engineering Works. The 2,000 kW set as illustrated in fig. 2, is of the combined type, in which the bottom half of the turbine exhaust casing and the condenser shell form one casting, thus reducing the dimensions of the foundations to a minimum and eliminating the usual condenser basement. The turbine, which is of the high pressure, multi-stage impulse type, runs at a speed of 6,000 r.p.m., and drives the alternator through totally enclosed helical gears to reduce the speed to 1,000 r.p.m.

The alternator is of the enclosed revolving field salient pole type, having a direct coupled exciter which is provided with interpoles to ensure sparkless running at all loads with fixed brush position.

A rheostat, mounted on the switchboard is inserted in the shunt field circuit of the exciter, and is capable of regulating under all conditions of load and power factor.

A surface type condenser is installed and is provided with a 4½ h.p. vertical motor driven condensate extraction pump and a steam-operated air ejector of the two stage type with a combined feed water heater. Cooling water for the condenser is provided by circulating water pumps, located in the pump house on the river bank. Two pumps are installed, one acting as standby. They are driven by 75 h.p. vertical slip ring motors which are provided with contactor control panels, fig. 3, remote controlled from the turbine room.

The 100 kW turbo set, fig. 4, which is used when the main 2,000 kW set is shut down, is of the high pressure impulse, back pressure type, running at a speed of 7,000 r.p.m. Totally enclosed helical gearing is provided to give an alternator speed of 1,500 r.p.m. The alternator is of the protected, revolving armature type, having an interpole type exciter, driven through a flexible coupling. As in the case of the 2,000 kW set, the exciter shunt field rheostat is mounted at the back of the switchboard.

MAIN SWITCHBOARD.

The main 380 volt flat back switchboard, fig. 2, is situated in the power station, and of the eleven panels comprising this board the first consists of a Brown Boveri

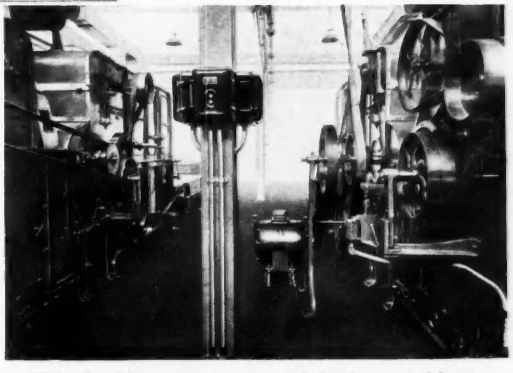


Fig. 5.—Hopper opener and feeder machines.

automatic voltage regulator while the second controls a 2,000 kW alternator. Owing to the heavy currents which have to be controlled, amounting to 2,800 amperes per phase, this panel is built in two sections.

On one section are mounted a 2,000 ampere, triple pole hand operated oil circuit breaker, fitted with three overload trip coils, and three 2,000 ampere single pole isolating links. On the other section is mounted similar equipment with the addition of a 200 ampere field switch, exciter regulator with handwheel and chain drive, time limit fuses, instrument fuses, current transformers, ammeters, voltmeter, etc. The two oil circuit breakers are connected in parallel and provided with the necessary interlocks.

The remaining panels control the 100 kW alternator, feeders to the mill, power station auxiliaries and lighting.

A swing panel equipped with a rotary synchroscope with lamps, and two sector pattern illuminated dial voltmeters, is hinged on the side of No. 1 panel of the main switchboard.

PROCESSES IN THE MILL.

A list of the motors and starters, with their respective duties, is given on page 281 in Table 1. The use of these motors and starters will be understood better by following the process of the cotton through the various departments in the mill.

The bales of raw cotton are delivered from the raw cotton store to the opening and mixing room. The cotton is here fed to the hopper bale breaker and thence through a series of opening and cleaning machines where the matted pressed cotton is opened and a proportion of the short fibre and dust content removed. This series of opening machines consists of the hopper feeders, Creighton openers, and horizontal openers, the first being shown in fig. 5. The opened cotton is then conveyed pneumatically to a condenser. The roving waster opener is installed to treat a quantity of the waste made in the later processes.

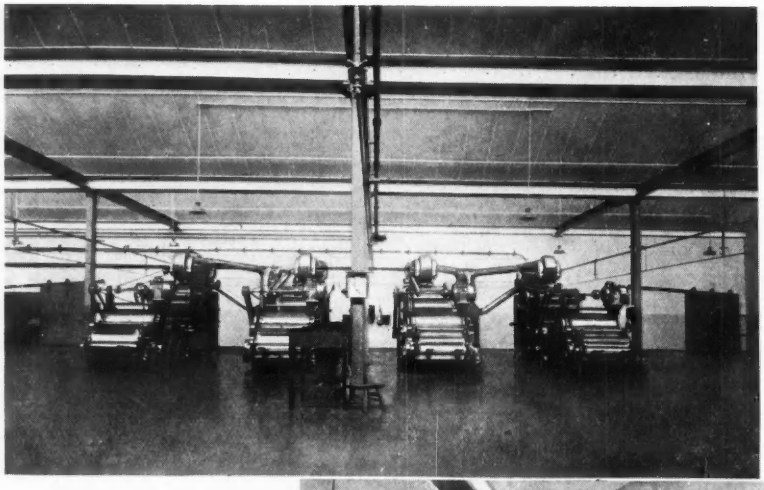


Fig. 6.—Scutchers used in the process of cotton cleaning.

The previously mentioned condenser feeds the cotton to the intake of a pneumatic trunk which in turn conveys it to the scutching room, where it is automatically distributed to the various batteries of machines for further cleaning. The machines consist of a hopper feeder giving a uniform and continuous supply of cotton to the scutcher where the cotton is struck by means of a quickly revolving beater and carried over a series of bars between which the short fibre, seed and sand, etc., are ejected. The good fibre is picked up by air current and carried to the surface of a pair of perforated rollers which deliver the cotton in the form of a sheet to the calender rollers. These rollers serve to consolidate the sheet into a form which enables the succeeding rollers to wind it into a roll formation, known as "lap," ready for the carding process.

Fig. 6 illustrates the scutchers, and it will be noted that the driving motors are of the totally enclosed cowl cooled type identical with those used for driving the ring spinning frames referred to later.

Cards.

The carding process consists of removing any dirt which may still remain in the cotton, finally delivering it in a rope form suitable for the next process.

The "laps," as delivered from the scutchers, are placed on revolving rollers at the entering end of the cards. As these rollers revolve, the laps unwind and are led into the machine by means of fluted rollers, to a circular saw type roller, called the "ticker-in,"

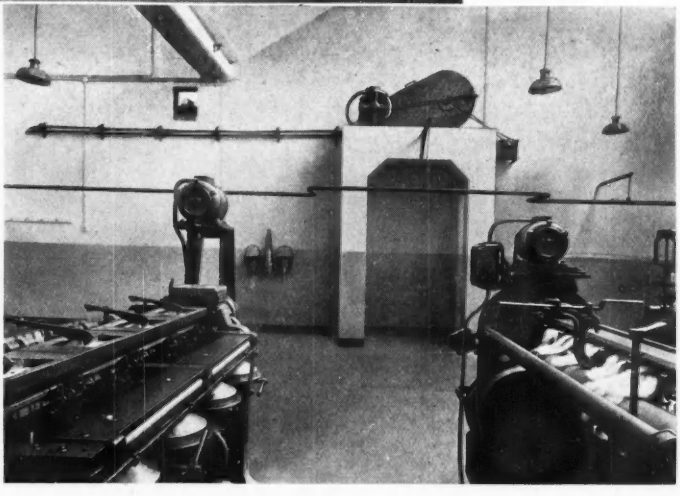


Fig. 7.—50 h.p., 975 r.p.m., High torque squirrel cage motor mounted on a structure against the wall, operating carding machines through chain drive. In the foreground are the sampling machines.

the teeth of which comb through the lap and pick up small tufts of fibre and carry them over grids through which further impurities escape. The good fibre is in turn picked up by a cylinder covered with fine wire, and in its passage to the front of the machine is further cleaned and eventually delivered in the form of a fleece which is drawn together in a rope, or "sliver," and fed into cans located at the side of the machine.

The cards are placed side by side in rows and are belt driven from pulleys on the overhead line shafting. There are three lines of this shafting each driven through a chain by a 50 h.p. 975 r.p.m. high torque squirrel cage motor. The motors and chain drives are mounted on platforms situated in rooms adjacent to the carding room, as shown in fig. 7.

A vacuum card stripping plant is installed in a room close to the cards and is driven by a 20 h.p. 2,900 r.p.m. squirrel cage motor.

TABLE I.

Drive.	Number	H.P.	Speed.	Type of Motor.	Type of Starter.
Hopper bale breakers and hopper openers	2	6	1440	S.C.T.E.	D.T.L. contactor.
Creighton openers	4	2	940	S.C.T.E.	D.T.L. contactor.
Hopper lattice feeders and condensers	2	6	1440	S.C.T.E.	D.T.L. contactor.
Roving waste openers and condensers	3	4	1440	S.C.T.E.	D.T.L. contactor.
Scutcher hopper feeders and condensers	4	9	1440	S.C.T.E.C.C.	D.T.L. contactor.
Carding engines	3	50	975	S.C.H.T.E.V.	Oil immersed star/delta.
Drawing frames	21	1½	1450	S.C.T.E.	D.T.L. contactor.
Speed frames	2	50	975	S.C.H.T.E.V.	Oil immersed star/delta.
Ring spinning frames	96	9	1440	S.C.T.E.C.C.	D.T.L. contactor.
Ring doubling frames	10	12	1450	S.C.T.E.C.C.	D.T.L. contactor.
Quick traverse winders	1	4	965	S.C.T.E.	D.T.L. contactor.
Cone winding	10	2	1455	S.C.T.E.	D.T.L. contactor.
Beam warping	4	1½	710	S.C.T.E.	D.T.L. contactor.
Pirn winding	7	6	1440	S.C.T.E.	D.T.L. contactor.
Card stripping	1	20	2900	S.C.E.V.	Oil immersed star/delta.
Sizing	1	35	975	S.C.E.V.	Oil immersed star/delta.
Looms	9	50	975	S.C.H.T.E.V.	Oil immersed star/delta.
Mechanics shop	1	15	720	S.C.E.V.	Oil immersed star/delta.
Humidifier	1	70	1470	S.C.H.T.E.V.	Oil immersed star/delta.
Humidifier	1	55	1470	S.C.H.T.E.V.	Oil immersed star/delta.
Plaiting machine	1	4	1460	S.C.T.E.	D.T.L. contactor.
Sampling machines	5	1½	1460	S.C.T.E.	D.T.L. contactor.
Joiners shop	1	15	720	S.C.E.V.	Oil immersed star/delta.
Roller covering	1	12	1450	S.C.T.E.C.C.	D.T.L. contactor.
Bracket screen, driving	1	10	720	S.C.T.E.	Air break star/delta.
Bracket screen washwater pump	1	4	960	S.C.E.V.	D.T.L. contactor.
Condenser circulating water pumps	2	75	1450	Vert. S.R. Protected.	Remote controlled contactor with rotor resistances.
Boiler induced draught fan	1	45	360	S.C.P.V.	Oil immersed star/delta.
Boiler economizer	1	2	1410	S.C.E.V.	3 pole ironclad with fuses.
Boiler chain grate stokers	3	1½	1410	S.C.T.E.	3 pole ironclad with fuses.
Make-up feed booster pumps	2	1	1410	S.C.E.V.	D.T.L. contactor with float switch.
Deep well air compressors	2	10	960	S.C.E.V.	D.T.L. contactor.
Condensate extraction pump (turbo set)	1	4½	1440	Vert. S.C. Protected.	D.T.L. contactor.
Condensate pump (heating system)	1	5	960	S.C.E.V.	D.T.L. contactor with float switch.
Baling press hydraulic pump	1	15	970	S.C.E.V.	Air break star/delta.
Creels	1	7½	950	S.C.E.V.	3 pole ironclad with fuses.
Spare motors	11	1½–50	710–1445	—	—

KEY TO SYMBOLS.

S.R.	Slip Ring.	S.C.H.T.E.V.	Squirrel Cage High Torque Enclosed Ventilated.
S.C.T.E.	Squirrel Cage Totally Enclosed.	S.C.T.E.C.C.	Squirrel Cage Totally Enclosed Cowl Cooled.
S.C.E.V.	Squirrel Cage Enclosed Ventilated.	D.T.L.	Direct to Line.
S.C.P.V.	Squirrel Cage Pipe Ventilated.		

Fig. 8.—Drawing frames driven by 1½ h.p. 1,450 r.p.m. squirrel cage motors.

Drawing Frames.

The cotton which leaves the carding machines in the form of a rope or sliver is now passed through the drawing frames, with the object of making the sliver more regular per unit length and of bringing the fibres into a parallel position with respect to each other. These frames are separately driven by 1½ h.p. motors through a V-belt drive, as shown in fig. 8.

Speed Frames.

The sliver from the drawing frames requires to be further drawn out and made more regular before it is in a suitable form for spinning into yarn. The machines used for this process are slubbing frames, intermediate frames and roving frames. These machines are arranged side by side in the correct sequence, and are belt driven from two overhead line shafts, each driven by a 50 h.p. 975 r.p.m. high torque squirrel cage motor through chain drives. As in the case of the carding machines the motors and chain drives are mounted on platforms located in adjacent corridors, and their oil immersed star/delta starters are placed in convenient positions for operating from the floor.

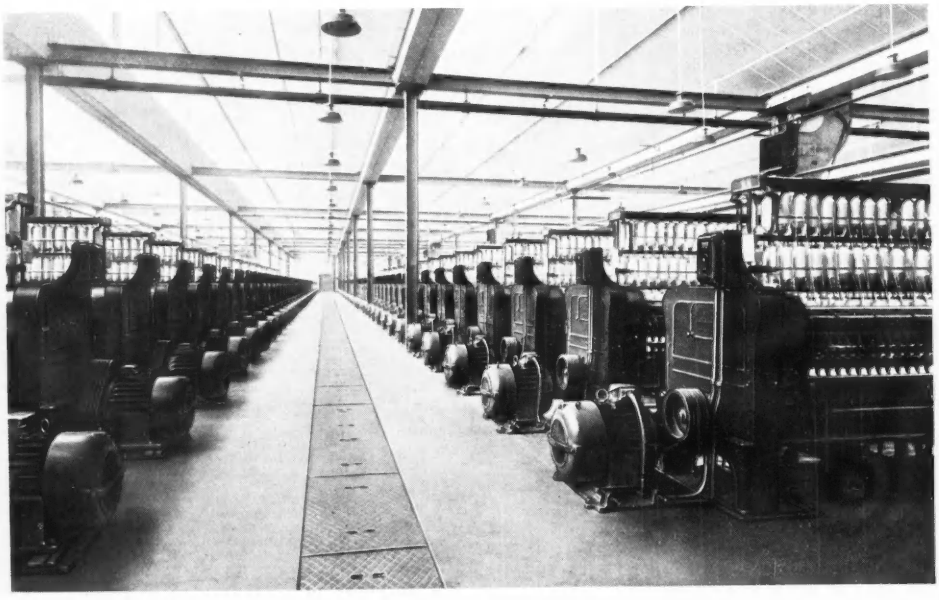


Fig. 9.—Ring spinning frames driven by a total of 96 9 h.p., 1,440 r.p.m. squirrel cage cowl cooled motors. The trench along the centre of the gangway accommodates bare copper bus bars.

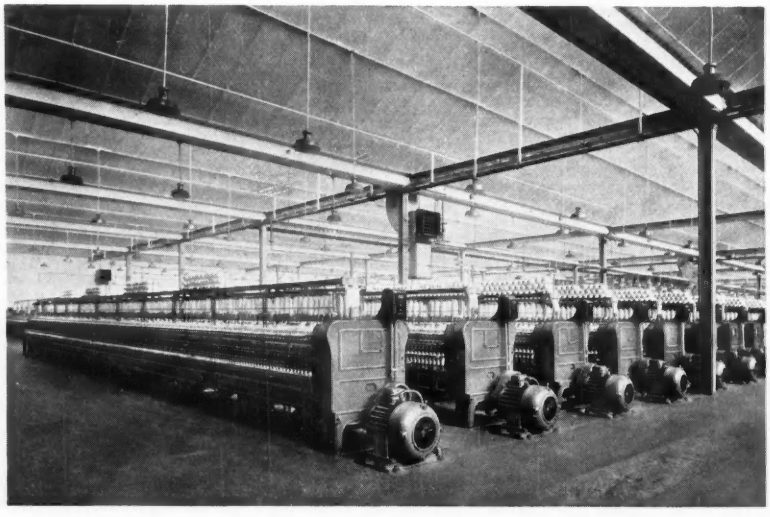


Fig. 10.—Another view of the ring spinning frames shown in fig. 9.

Spinning Frames.

The method of spinning adopted is known as ring spinning, and the process consists of drafting out the roving from the previous process, and imparting a twist to give the yarn the necessary strength.

The spinning frames are separately driven through V-belts by 9 h.p. totally enclosed cowl cooled motors. It is of interest to note that experiments were conducted in order to produce a motor capable of giving the necessary gradual starting characteristics to prevent the cotton breaking. These experiments resulted in a design of motor which has proved to be most successful in operation. The motors together with their respective starters are shown in figs. 9 and 10.

Cheese Winders.

Cheese winders are installed for assembling the threads in a form suitable for the doubling frames and are direct driven by 4 h.p. squirrel cage motors.

Ring Doubling Frames.

Dry process doubling is adopted. As the name implies, the function of a ring doubling frame is to double the threads together to produce an elastic and smooth yarn. Ten of these machines are installed and are separately driven by 12 h.p. totally enclosed cowl cooled motors through V-belts. The motors with their respective starters are shown in fig. 11.

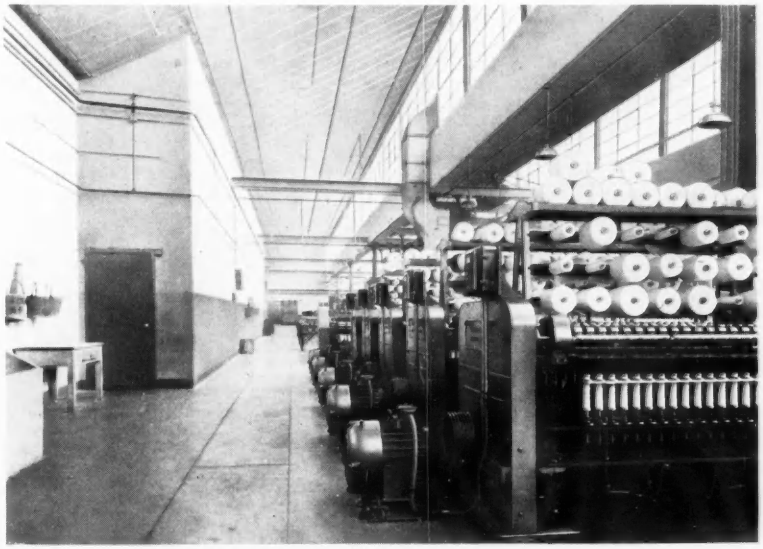


Fig. 11.—12 h.p. 1,450 r.p.m. Squirrel cage cowl cooled motors driving ring doubling frames.

Cone Winders.

Cone winders are employed solely for the purpose of rewinding the cotton from the doubling frame bobbins into a larger cone shaped formation ready for the beam warping machine. The winders are two sided, each side being driven by a 2 h.p. totally enclosed motor with direct-to-line contactor starter, as illustrated in fig. 12.

Beam Warping.

The warp is wound by beam warping machines on to suitable beams ready for the slasher sizer. Some thousands of cotton ends are frequently wound on to one beam and a friction clutch automatically disengages the machine in the event of one of the ends breaking. These machines are separately driven by V-belts, the larger pulley being combined with a friction clutch, as indicated in fig. 15.

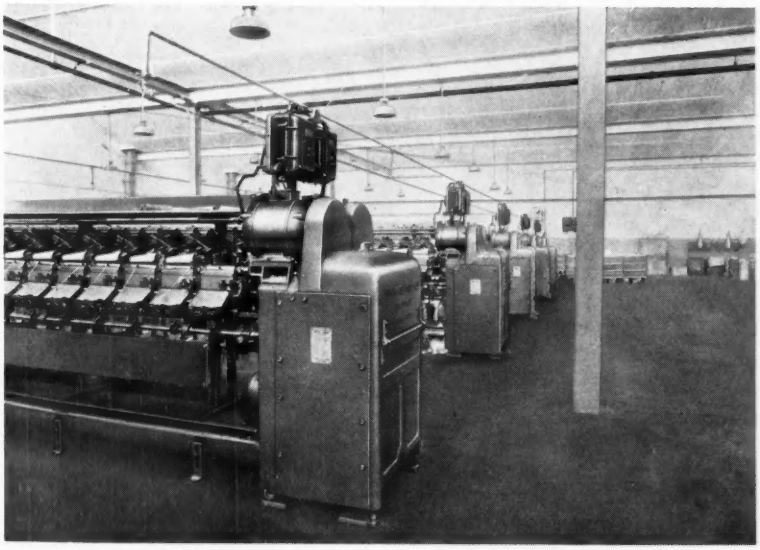


Fig. 12.—Double sided cone winders driven by 2 h.p. 1,455 r.p.m. squirrel cage motors.

Slasher Sizing.

The slasher sizer impregnates the warp with suitable size to enable it to withstand the strain of weaving. The process consists of taking the threads of a number of beams over guide rollers through a trough of boiling size and then through further rollers which squeeze out any excess size and moisture. The threads are then dried by passing over steam-heated cylinders, and re-wound on to a weavers beam at the delivery end of the machine. Four of these slasher sizers are installed and are driven by belt from a line shafting which in turn is belt driven by a 35 h.p. squirrel cage motor mounted on the floor.

Size boiling and mixing becks, driven from a second line shaft, are installed to provide the necessary size for the slasher sizers.

Pirn Winders.

A number of pirn winding machines are installed to wind the yarn or weft from the spinning frames on to suitably shaped pirns to fit the loom shuttles. These machines are separately belt driven

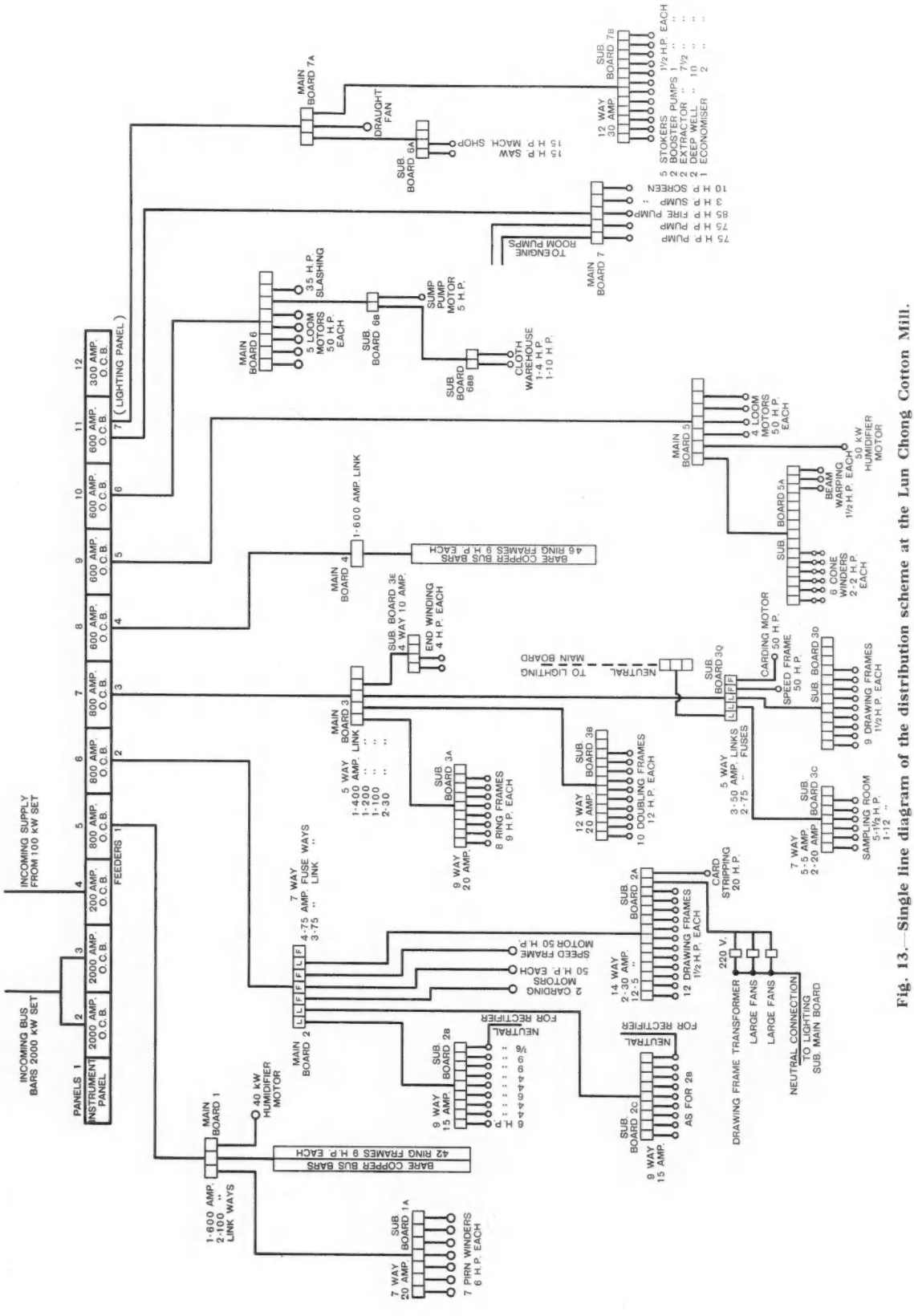

INCOMING BUS BARS 2000 KW SET
INCOMING SUPPLY FROM 100 KW SET
PANELS 1
INSTRUMENT PANEL
2000 AMP. O.C.B.
200 AMP. O.C.B.
800 AMP. O.C.B.
600 AMP. O.C.B.
300 AMP. O.C.B.
FEEDERS 1
(LIGHTING PANEL)
MAIN BOARD 1
MAIN BOARD 2
MAIN BOARD 3
MAIN BOARD 4
MAIN BOARD 5
MAIN BOARD 6
MAIN BOARD 7
MAIN BOARD 7A
SUB BOARD 1A
SUB BOARD 2A
SUB BOARD 2B
SUB BOARD 2C
SUB BOARD 3A
SUB BOARD 3B
SUB BOARD 3C
SUB BOARD 3E
SUB BOARD 3Q
SUB BOARD 5A
SUB BOARD 6A
SUB BOARD 6B
SUB BOARD 6BB
SUB BOARD 7B
40 KW HUMIDIFIER MOTOR
1-600 AMP. 2-100 " LINK WAYS
7 WAY 20 AMP
7 PIRN WINDERS 6 H.P. EACH
42 RING FRAMES 9 H.P. EACH
BARE COPPER BUS BARS
9 WAY 15 AMP.
4-75 AMP. FUSE WAYS 3-75 " LINK "
SPEED FRAME MOTOR 50 H.P.
2 CARDING MOTORS 50 H.P. EACH
14 WAY 2-30 AMP. 12-5 "
12 DRAWING FRAMES 1½ H.P. EACH
CARD STRIPPING 20 H.P.
FOR RECTIFIER
NEUTRAL
AS FOR 2B
5 WAY 1-400 AMP. LINK 1-200 " 1-100 " 2-30 "
9 WAY 20 AMP.
8 RING FRAMES 9 H.P. EACH
12 WAY 20 AMP.
10 DOUBLING FRAMES 12 H.P. EACH
1-600 AMP. LINK
BARE COPPER BUS BARS 46 RING FRAMES EACH
SUB BOARD 3E 4 WAY 10 AMP.
END WINDING 4 H.P. EACH
NEUTRAL
TO LIGHTING MAIN BOARD
5 WAY 3-50 AMP. LINKS 2-75 " FUSES
CARDING MOTOR 50 H.P.
SPEED FRAME 50 H.P.
9 DRAWING FRAMES 1½ H.P. EACH
7 WAY 5-5 AMP. 2-20 AMP.
SAMPLING ROOM 3½ H.P. 1-12 "
4 LOOM MOTORS 50 H.P. EACH
50 KW HUMIDIFIER MOTOR
BEAM WARPING 1½ H.P. EACH
6 CONE WINDERS 2½ H.P. EACH
35 H.P. SLASHING
5 LOOM MOTORS 50 H.P. EACH
SUMP PUMP MOTOR 5 H.P.
CLOTH WAREHOUSE 4 H.P. 1-10 H.P.
TO ENGINE ROOM PUMPS
75 H.P. PUMP
85 H.P. FIRE PUMP
3 H.P. SUMP
10 H.P. SCREEN
DRAUGHT FAN
15 H.P. SAW MACH. SHOP
12 WAY 30 AMP.
5 STOKERS 1½ H.P. EACH
2 BOOSTER PUMPS 7½ " "
2 EXTRACTOR " 10 " "
2 DEEP WELL " 2 " "
1 ECONOMISER
220 V.
DRAWING FRAME TRANSFORMER
LARGE FANS
LARGE FANS
NEUTRAL CONNECTION TO LIGHTING SUB. MAIN BOARD

Fig. 13.—Single line diagram of the distribution scheme at the Lun Chong Cotton Mill.

by 6 h.p. totally enclosed motors, as shown in fig. 14.

Weaving.

Group drive has been adopted throughout for the looms. Nine 50 h.p. high torque squirrel cage motors driving two lines of shafting by chain are installed on platforms located in a corridor adjacent to the weaving shed. Two of these motors with chain drive are shown in fig. 16. The control gear for each motor comprises an oil immersed star/delta starter fitted with an ammeter.

Roller Covering.

Special machines are also installed to re-cover the rollers of the spinning and cardroom machinery. These machines are belt driven from a line shaft, the 12 h.p. driving motor being located on the floor in one corner of the room.

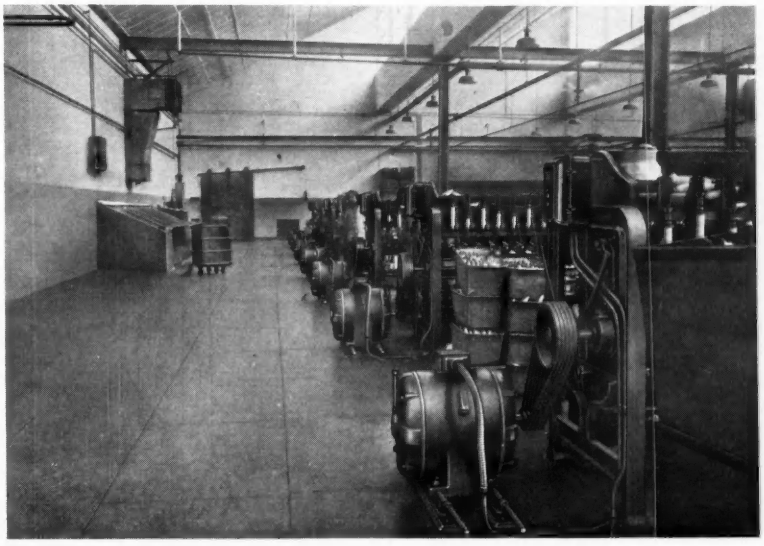


Fig. 14.—Pirn winding machines driven by 6 h.p., 1,440 r.p.m. squirrel cage totally enclosed motors.

Making Up.

After leaving the loom the cloth goes through the final stages of manufacture which consists of brushing, shearing off loose ends, plaiting down and pressing into suitable bundles. The plaiting machines are driven by a 4 h.p. squirrel cage motor by belting from a line shaft, whilst the hydraulic pump for the bundling press is driven by a 15 h.p. motor.

The cloth is now finished and ready for transporting to the company's bleaching, printing and finishing works.

Sampling Room.

In order to determine the correct cotton mixings, strength, and spinning quality of the various cottons, experimental machines are installed in a sampling room. These machines comprise drawing, intermediate, ring spinning frames, etc., and are separately driven.

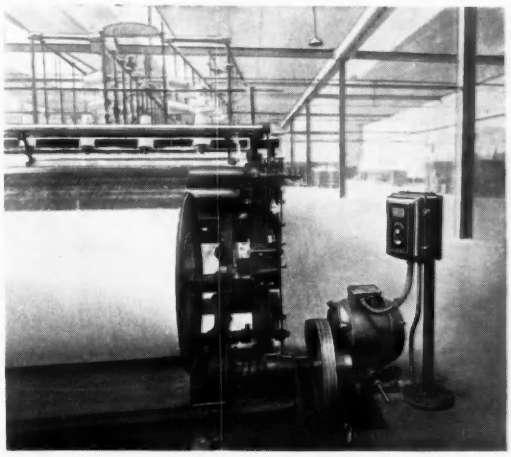


Fig. 15.—Beam warping machine driven by 1½ h.p., 710 r.p.m. squirrel cage totally enclosed motor.

Humidifying.

Two humidifying plants, one for the spinning mill and one for the weaving mill, are installed to maintain the relative humidity of the air necessary for the spinning and weaving. These plants are driven by 70 h.p. and 55 h.p. motors respectively, and are controlled by oil immersed star/delta starters, fig. 17.

POWER DISTRIBUTION.

Power is distributed from the main feeder panels in the power house, by Pirelli-General paper insulated, lead covered and armoured cables laid underneath the ground between the power house and the various buildings. Trenches are provided in the floors of the buildings for the cables, which are led to main fuse and link distribution boards, thence to sub-distribution fuse boards, and finally to the control gear of the various motors. Fig. 13 shows a single line diagram of power distribution from which the various circuits can easily be traced.

The method of distribution from boards MB1 and MB4 to the ring spinning frame starters and motors should be particularly noted. After consideration of the various methods available it was decided to adopt a bus bar system arranged in a trench between the two lines of ring spinning frames. The bare copper conductors are arranged with the three phases one above the other to prevent short circuits occurring due to objects being accidentally dropped across the phases. The bus bars are supported on Sindanyo panels and tappings are taken through fuses into a conduit laid underneath the floor to the motor starters which are fixed on to the end frames of the machines. Special waterproof covers are provided for this trench to prevent ingress of water.

It will have been noted from the description of the processes in the mills, that there are many small motors driving various machines in different parts of the mill. The conduit carrying cables to these motors is laid in the sub-floor of the mill before the surface floor was laid, or any of the machines erected.

LIGHTING AND HEATING.

A large number of lighting, heating and ventilating points are provided throughout the various sections of the mill. These are as follows :—

Spinning Mill Section.

Lighting points	603
Lighting plug points	21
Heating plug points	6
Electric siren	1
Unit heaters and exhaust fans	28
Inlet fans	7

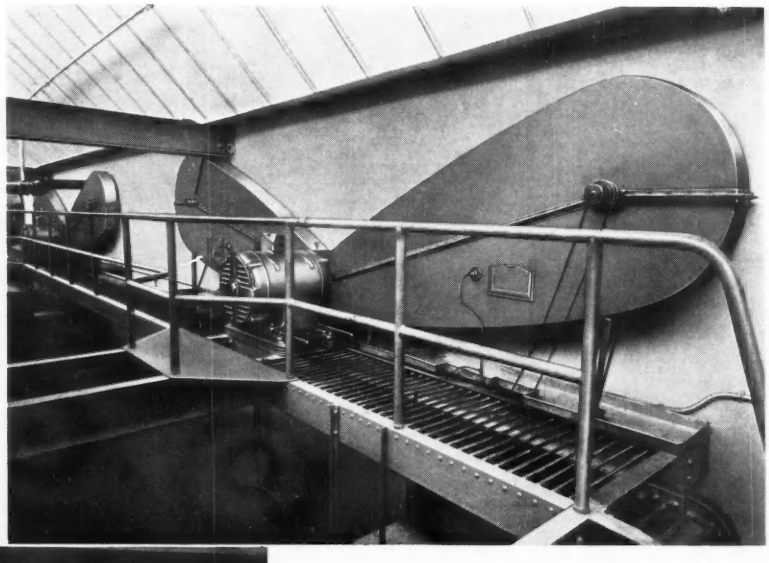


Fig. 16.—Two of the 50 h.p., 975 r.p.m., high torque squirrel cage motors driving line shafting for the weaving looms.

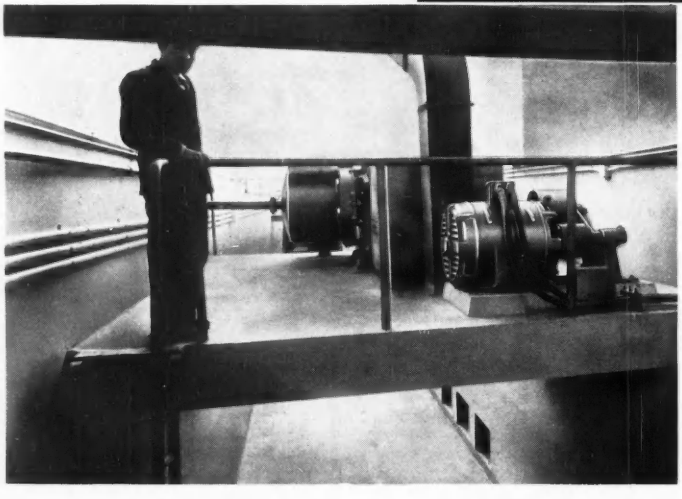


Fig. 17.—Humidifying plants for spinning and weaving mills, driven by 70 h.p. and 55 h.p. 1,470 r.p.m. squirrel cage high torque motors respectively.

Weaving Mill Section.

Lighting points	765
Lighting plug points	8
Electric siren	1
Unit heaters and exhaust fans	32
Inlet fans	6
Push button stops for 50 h.p. motors	9

Power Station Buildings.

Lighting points	74
Lighting plug points	16
Heating plug points	4
Ceiling fans	1
Unit heaters	1

Pump House and Jetty.

Lighting points	7
Lighting plug points	4

Searching Rooms and Watchmen's Offices.

Lighting points	15

Offices and Residences.

Lighting points	120
Ceiling fans with lights	12
Lighting plugs	39
Bells	11
Heating plugs	6

As in the case of the power distribution, P.I.L.C.A. cables are used from the feeder panel in the power house to the main distribution boards in the various buildings. From these boards to the sub-distribution boards and thence to the various lighting, heating and other points, V.I.R. cable run in galvanized conduit is used.

LIGHTING AND HEATING.

For the lighting, heating and ventilation of the various sections of the mill over 1,580 lighting points have been installed, 88 lighting plug points, 61 unit heaters and exhaust fans, 16 heating plug points and 26 inlet fans and ceiling fans. As in the case of the power distribution, P.I.L.C.A. cables are used between the lighting feeder panel in the power house and the main distribution boards in the buildings. V.I.R. cable enclosed in galvanized conduit is then used to distribute to the sub-distribution boards. As regards the lighting fittings, over 1,400 dispersive reflectors are installed, equipped with lamps ranging from 40 to 500 watts.

In conclusion, acknowledgement is due to the directors of the China Printing and Finishing Co., Ltd., for their kindness in giving permission for the publication of the information and illustrations contained in this article.

Cooking Equipment at Gatwick Aerodrome.

Extensive arrangements have been made at Gatwick aerodrome for catering and providing refreshment for visitors.

The restaurant has accommodation for 60 people. Its all-electric kitchen has been equipped throughout with modern G.E.C. cooking apparatus. A spacious hotcupboard with serving top, ensures a service of hot meals at any time ; there is also a specially designed pressure boiler, delivering 120 pints of boiling water per hour, together with coffee and milk urns.

Automatic Control of Road Traffic.

WITH PARTICULAR REFERENCE TO THE "AUTOFLEX" SYSTEM.

PART II.

By F. A. DOWNES, A.M.I.E.E., M.I.R.S.E.
Traffic Engineer, The Siemens and General Electric Railway Signal Co., Ltd.

VEHICLE DETECTORS.

THERE are three types of vehicle detector at present in use with vehicle-actuated systems.

Direct Contact Detector.

The first type, which was the original detector imported from America, consists of a sealed rubber package containing a pair of contact strips. On being traversed by the vehicle, the rubber package is flexed and the contacts closed for a period proportional to the time of traverse of the vehicle. Where it is necessary to make the vehicle detector unidirectional, two pairs of strips are provided side by side and are connected by means of a 3-core cable to electrically interlocked relays in the controller. It is usual in the case of this detector to provide a renewable rubber tread over the sealed package.

Autoflex Detector.

The second type of detector is that used with the Autoflex system.[1] This is a development of the Siemens and General Electric Railway Signal Co., Ltd., and its design is particularly interesting. It consists of two portions—the actual rubber pad and the electrical contact box. The pad is situated in the carriageway and the contact box in the pavement or other convenient location. A section of the pad is shown in fig. 1. It consists of an internal rubber moulding containing two elliptically sectioned air channels. This rubber moulding is laid on a steel bed-plate and covered by a protective tread held in place by longitudinal strips of steel. The whole framework is strengthened by diagonally placed steel angles which are shown in fig. 2. Both ends of the air channels are closed, but access is made through two nipples placed close to one end of the pad. These two nipples are connected by means of galvanized steel pipes to the contact box, fig. 3.

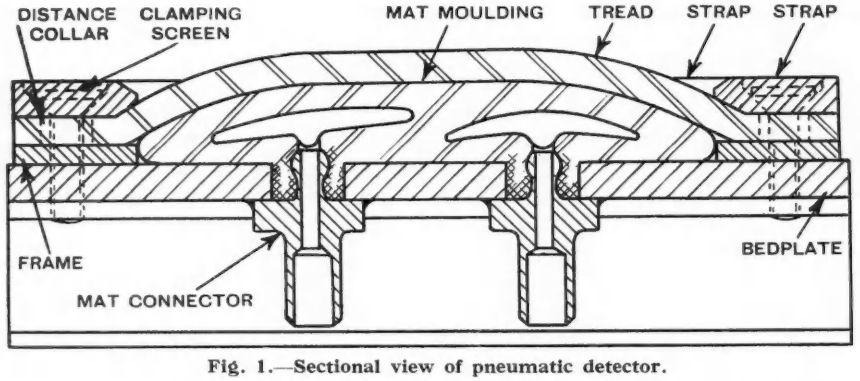


Fig. 1.—Sectional view of pneumatic detector.

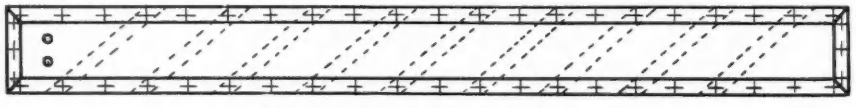


Fig. 2.—Plan of pneumatic detector.

Reference to this figure will reveal two steel flaps housed in an inner die cast aluminium case. Underneath each flap is an opening connected to the appropriate pipe leading to one or other of the air channels. The bottom edges of each of the two flaps are hardened to form wear-resisting interlocking surfaces. The space between the flap and the entrance hole below is occupied by a double leather diaphragm which acts as a miniature bellows. One of the flaps only is provided with a silver contact and mounted above this contact is an adjustable contact screw carried on a bakelite bridge, as shown in the illustration.

The action of the complete detector is as follows: If a vehicle traverses a pad in the right direction,

1. "G.E.C. Journal" Vol. VII., No. 3, p. 208.

air is expelled from one side of the pad, which lifts the contact flap and closes the electrical contact. Immediately afterwards, as traverse of the pad continues, air is expelled from the other air channel, but the other flap cannot rise as it is prevented by the locking face of the contact flap. If a vehicle traverses the pad in the wrong direction, then the

Fig. 3.—Contact box opened to show construction.

above sequence of events is reversed and the blank flap picks up first and so prevents the contact flap from lifting and completing the electrical circuit. The inner housing which carries these two flaps is quite small and readily removable for maintenance purposes. The joint between the inner housing and the seating is not an air-tight seal but consists of a pair of thick felt washers. The use of the felt

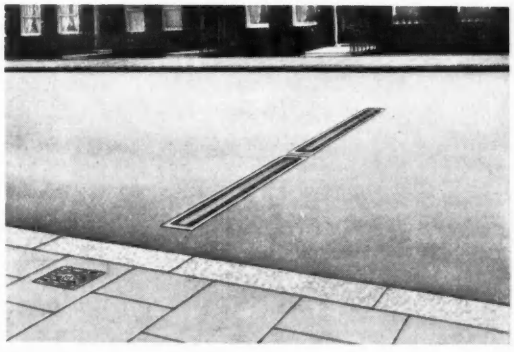


Fig. 4.—Relative positions of detector pads and contact box.

washers allows the air pressure in the system to equalize itself after operation by filtering through the interstices of the felt.

Vehicle detectors are generally made up in lengths of 3, 6, 8 and 10ft. Where a detector length greater than 10ft. is required a number of pads can be used with the air pipes connected in parallel. Fig. 4 shows a detector layout employing 7ft. 6in. and 5ft. detectors.

Light Ray Detector.

The third type of detector uses light rays in conjunction with photo-electric cells, but this system of vehicle detection is of limited application, as it can only be used where there are separate carriageways for up and down traffic.

Characteristics of Vehicle Detectors.

The first type of detector, incorporating the direct electrical contact is used in conjunction with the Electromatic system and, although the time of contact closure is proportional to the time of traverse of the vehicles, this characteristic is not utilized as

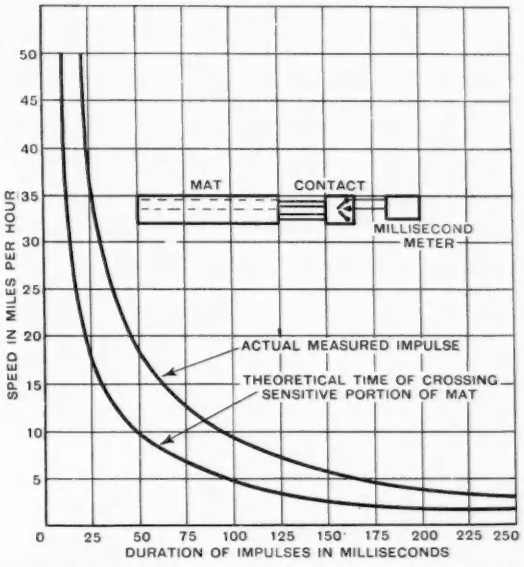


Fig. 5.—Response curve of vehicle detector for two axles.

the Electromatic controller provides a fixed increase of green time for every vehicle.

With the Autoflex system, however, it is necessary to measure the approximate speed of vehicles traversing the pad, and fig. 5 is a response curve of the Autoflex vehicle detector for two axles. It will be noticed that the shape of the curve representing the actual measured impulse follows very closely the outline of the calculated curve. The curve shows the relation between the duration of the contact closure in milliseconds and the speed of the vehicle in miles per hour. The curve has reference, of course, to the half of the rubber pad connected to the contacting member of the contact box.

An interesting point in connection with the design of the Autoflex vehicle detector is the necessity for providing some form of damping in the air system. Without such damping there is a tendency for the air in the system to oscillate, and fig. 6

reproduces actual air oscillograms with and without damping baffles. The damping baffles consist of a few feet of hard drawn copper wire on which is sweated a number of small brass balls of slightly less diameter than the steel connecting pipes. A sufficient length of this baffle wire, as it is termed, is pushed into the two main connecting pipes to provide the requisite amount of damping. Owing to the unidirectional feature being provided in the contact box of the pneumatic type of detector, a 2-core cable only is required. With the electric and photo-electric types, a 3-core cable is generally employed.

TIMING CIRCUITS AND THEIR CHARACTERISTICS.

Normal Timer.

A circuit diagram of the normal timing circuit is given in fig. 7.

The principle of operation is as follows. When the control contact is lying in the position shown, the condenser charges through the charging resistance until its potential is equal to that of the supply, after which no further flow of current takes place. When it is required to measure off the period of time, the control contact is transferred to the opposite side

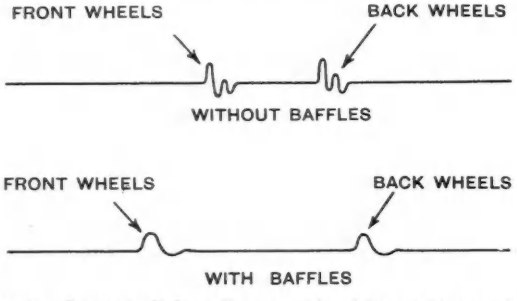


Fig. 6.—Pneumatic impulse records of standard Autoflex detector showing the effect of baffles.

and the condenser discharges through the discharge resistance. As the voltage across the condenser falls, so the voltage across the neon tube and relay rises until the striking point of the neon tube is reached. The neon tube then strikes and the relay is energized. The range of periods which can be timed with this timer can be adjusted by varying the discharge resistance. This normal timer circuit forms the basis of the minimum green, maximum green and amber circuits.

Speed Timer.

The circuit used in the speed timer is shown in fig. 8. It is similar in principle to the normal timer, and the operation is as follows :—

With the contact on relay RW in the normal position condenser QA completely discharges through resistance R1 and in such circumstances the neon tube would strike immediately contact DE closes.

RW, however, is operated by vehicles traversing the detectors in the roads which have right-of-way and upon its position being reversed and the upper contact closed condenser QA will be charged to an extent inversely proportional to the vehicle speed, so preventing immediate striking of the neon tube. Values for

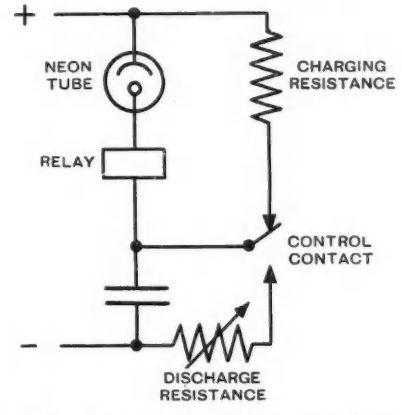


Fig. 7.—Circuit diagram of normal timer.

R and R1 are so chosen that the charge on QA has leaked away through RW by the time the vehicle has traversed the intersection.

Contact DE is on the demand relay and indicates a demand from a vehicle for right-of-

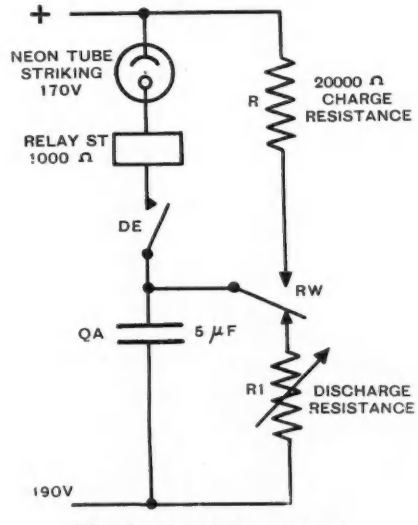


Fig. 8.—Speed timer circuit.

way ; the conditions under which DE operate are described later.

It is interesting to examine more closely the characteristics of this speed timer circuit.

Fig. 9 is a family of curves showing the rate of discharge of condenser QA for various values of resistance R1. It is the usual practice in Autoflex traffic controllers to provide four alternative values

for R1 in order that the speed timer characteristics can be adjusted to suit the intersection at which the controller has to function. The shape of the curve generally agrees quite well with the actual requirements to which the speed timer should conform in practice, and the results obtained in conjunction with the Autoflex vehicle detector are very satisfactory. It is only in the case of very slow vehicles, such as horse-drawn lorries, etc., that any discrepancies are noticeable. The problem of slow moving vehicles involves rather more than the provision of a speed time circuit having special characteristics. This matter is receiving special attention, and developments may be expected shortly.

TWO PHASE CONTROLLER CIRCUIT AND OPERATION.

A series of diagrams is given in fig. 10, which have been drawn in a simplified form to enable the operation of the simple 2-phase controller to be understood easily, and it should be borne in mind that these circuits, whilst showing the essential circuits, have been stripped of all the ancillary circuits.

This figure is divided into nine sections, lettered (a) to (i), and the small letters in brackets in the description of the circuit provide an easy means of identifying the particular relay or contact which is being described.

Two important relays RW and DE (a) are connected to contacts of relay RC in such a manner that they are switched to the vehicle detector contacts of roads A and B respectively, when relay RC is de-energized, and to the detector contacts of roads B and A when RC is energized.

RW (b) is provided with a contact which discharges the speed timer condenser QA through contact MTA and the appropriate resistance.

It will be seen that each impulse from the detector operates RW relay, and recharges the condenser through the charging resistance and contact CO in proportion to the time taken by the vehicle to traverse the detector. The ratio of the charge and discharge resistances is so arranged that the rate of discharge of QA bears a suitable relationship to the speed of vehicles traversing the detector and is so calculated that the neon tube cannot strike until such time as the last vehicle has had sufficient time to traverse the intersection (subject to control of the maximum timer referred to later).

Upon the demand from the detector being received, relay DE (a) is energized and locks through contact DE and contact STA. Contact DE (b) is now closed and connects the neon tube and relay ready for striking, and another contact DE (d) starts the discharge of the maximum green condenser QB. Should no further vehicles traverse the detector in the road having right-of-way, the speed timer neon tube will now strike and relay ST (b) and its relief relay STA will be energized. Should there be a succession of vehicles passing over the detector so frequently that condenser QA is not fully discharged, QB (d) will discharge first and so energize relay MT and its relief MTA. This will mark the termination of the maximum green period—in other words, a continuous flow of vehicles has been forcibly interrupted as they have exceeded the maximum limit prescribed in the fundamental controller requirements laid down in Part I. of this article. Should the maximum green timer have operated, as described above, relay MTA (e) will be locked by means of its own contact MTA, which is energized through contact ATA. Contact MTA (c), on opening, leaves resistance in circuit, and this has the effect of increasing the amber period by a predetermined amount. Contact MTA (b) quickly discharges condenser QA through resistance YB and immediately allows the speed timer neon tube to strike. The striking of this neon tube will operate relays ST and STA, as previously described.

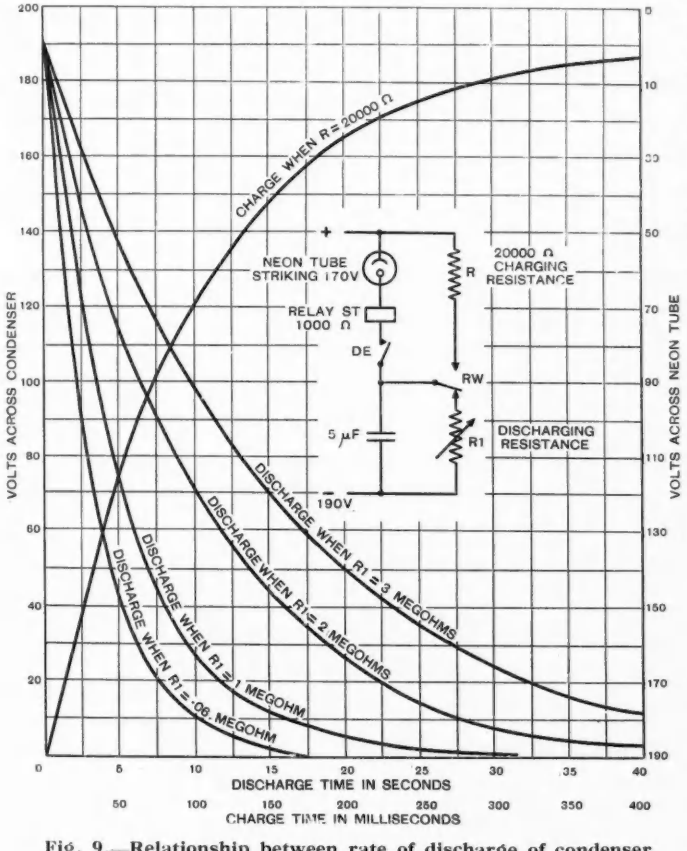
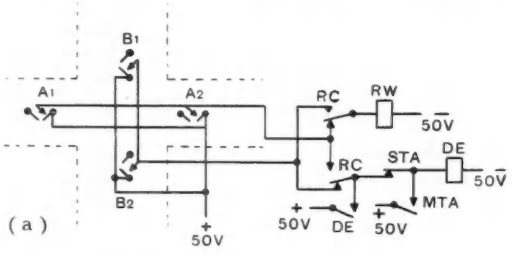


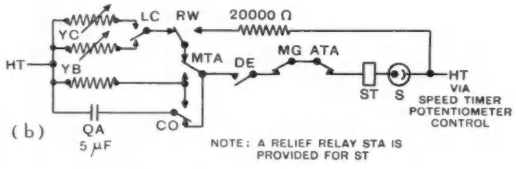
Fig. 9.—Relationship between rate of discharge of condenser QA (fig. 8) for various values of R1.

Contact MTA (a) will lock DE so as to record a demand for the return of right-of-way to the road from which it has been taken—that is to say, if a stream of traffic has been broken into by the functioning of the maximum timer, the controller will remember that there are still vehicles waiting in the stream of traffic which has been interrupted. ST and STA, having operated as previously described, will cause contact STA to release relay DE (a) unless MTA has operated. This means that the demand relay DE is now free to accept another demand should the maximum timer relay MTA have not already taken precedence by storing a demand.

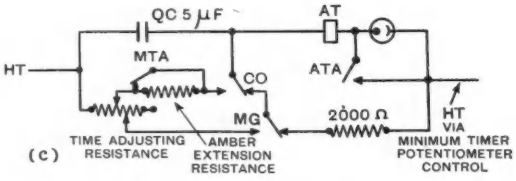
Contact STA operates relay AMA (f), relay AM and relay CO, which lock through contacts AMA and ATA. Contact CO (b) disconnects the speed timer from the supply and completely discharges condenser QA ready for further use. Contact CO (d) will recharge condenser QB.



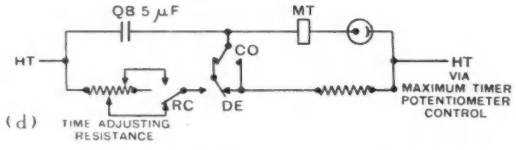
(a) Detector switching circuit.



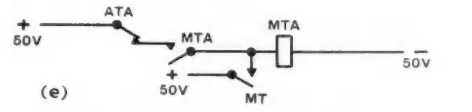
(b) Speed timer circuit.



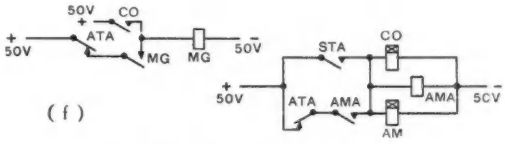
(c) Minimum green and amber timer circuit.



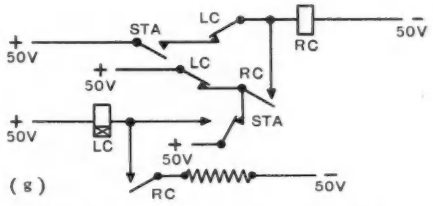
(d) Maximum green timer circuit.



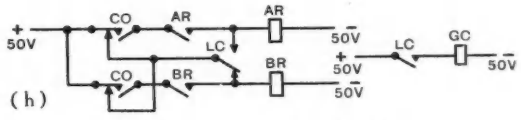
(e) H.T. relay relief circuit.



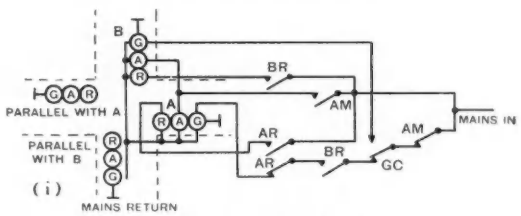
(f) Amber control circuit.



(g) Road and lamp relay circuit.



(h) Lamp contactor circuit.



(i) Signal lamp circuit.

KEY TO SYMBOLS:

AM	..	Amber contactor.	MG	..	Minimum green relay.
AMA	..	Amber relay relief.	MT	..	Maximum timer relay.
AR	..	"A" road red contactor.	MTA	..	Maximum timer relay relief.
AT	..	Amber timer relay.	RC	..	Road connecting relay.
ATA	..	Amber timer relay relief.	RW	..	Right-of-way relay.
BR	..	"B" road red contactor.	ST	..	Speed timer relay.
CO	..	Changeover relay.	STA	..	Speed timer relay relief.
DE	..	Demand relay.	QA	..	Speed timer condenser.
GC	..	Green contactor.	QB	..	Maximum timer condenser.
LC	..	Lamp control relay.	QC	.	Minimum and amber timer condenser.

Fig. 10.—Diagrams showing in simplified form the operation of a 2-phase controller.

Contact CO (c) proceeds to discharge the amber timer condenser QC. The contacts on relay CO (h) will disconnect contact LC and so prevent immediate operation of the red lamp relays of the road from which right-of-way is being taken. The relay contact symbol, diagram (h) is intended to indicate that these CO contacts make with the upper contact

before breaking with the lower contact. Contact CO (f) operates relay MG, which is locked by its own contact and contact ATA. Relay AM (f) and (i) now connects the amber lamps and disconnects the green lamps.

Relays RC and LC (g) being energized or de-energized, will change over the vehicle detector connections (a) by means of contacts on RC and will prepare the circuits for the new conditions whilst LC will prepare the appropriate circuits (h) for the red and green contactor relays AR, BR and GC.

Upon the striking of the amber timer neon tube, relays AT and ATA will be energized (c). Contact ATA (f) will release relay AMA, and contact AMA will prevent continued operation of the slow releasing relays AM and CO after the release of ATA. Relay CO is slow to release, and so will not restore before the end of the pulse, and by means of one of its contacts will prevent the release of MG. On the release of contacts CO and ATA, relay MG will lock its own contact and contact ATA, as before. The release of relay CO (h) will disconnect the red contactor relay of the road receiving right-of-way, and, in turn *via* contact LC, connect the red contactor of the road about to lose the right-of-way. A new discharge of condenser QC (c) is started by contacts CO and MG to measure off the minimum green period. On the termination of the minimum green period, relays AT and ATA (relief relay) will operate. Contact ATA (f) will release relay MG. A contact on MG (b) will complete the circuit of the speed timer for fresh demands. Another contact on ATA will stop the immediate operation of the speed timer on the closing of the above mentioned contact on MG as, otherwise, there will be no lock circuit for relay CO when contact STA closed, until after ATA had been restored to normal.

2-PHASE CONTROLLER—MEANS OF ADJUSTMENT.

Timer Adjusting Switches.

In the plain 2-phase controller, as described in the foregoing circuit, it will be appreciated that provision must be made for adjusting the various timers. The different resistances, which are shown adjustable on the diagram, are divided into ten sections, the common connection between each section being connected to the appropriate studs on a ten point rotary switch.

In the 2-phase controller, the following timer adjusting switches are provided :—

"A" Road. Minimum green switch, 10 steps. Calibrated as follows :—8, 9, 10, 11, 12, 14, 16, 18, 20 and 25 seconds.

Maximum green switch 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 seconds.

"B" Road. Minimum green switch and a maximum green switch, calibrated exactly as for the "A" road.

A common amber switch is provided, calibrated as follows :—1 – 10 in one second steps.

Calibration of Timing Dials.

Owing to slight differences in the characteristics of individual neon tubes, it is necessary to provide some means of recalibrating the dial readings when a tube is changed. To accomplish this, the supply to each timing circuit is fed from a potentiometer giving a range of 40 volts above and 40 volts below the nominal figure, *i.e.*, a total range of 80 volts, which is sufficient to cover all normal requirements.

Hand Control Switch.

A hand control switch is provided which has the following positions :—

1. Normal (vehicle-actuated operation).
2. Fixed time operation.
3. "All red."
4. Hand control.

This four position switch, when in the Normal position, allows the controller to operate in a normal vehicle-actuated manner, as in the foregoing description of operation, but when turned to the Fixed Time position disconnects the return circuit from the vehicle detectors and renders them ineffective. It also connects the normal maximum green timer circuit in such a manner that condenser QB is discharged through its normal discharging resistances so that the neon tube continues to flash at the predetermined setting of the maximum green switch. The periods for each road can be separately adjusted by means of the "A" and "B" maximum green switches respectively, the RC contact selecting the maximum timer resistance, as shown in the diagram, determining the alternate selection of the two periods.

In the "All Red" position, the switch disconnects the feed to the relay contacts controlling the green and amber lamp contactors, and completes the circuits of the "A" and "B" road red lamp relays.

When the switch is turned to the "Hand Control" position, the return circuit is again removed from the vehicle detectors and the hand control push button is connected in the circuit of relay MTA. Under these circumstances, if relay MG is de-energized, relay MTA can be operated and a complete changeover effected by depressing the push button. In order to prevent misuse of the push button by offering amber and "go" periods too short to be of any use, the operation is controlled during the amber and minimum green period by a contact on relay MG. This will prevent any change being made until the normal amber and minimum green periods have expired.

Revert Switches.

It is usual to provide two revert switches in a

2-phase controller, one each for phases A and B, and the function of these switches, as their name implies, is to provide a circuit whereby the controller can be arranged to return the green to the road for which the revert key is operated. This is often necessary should one or other of the roads be an arterial or main road, and its correct use is often the means of assisting traffic flow in a busy thoroughfare as during such time as the green is not required by the side road the controller will automatically transfer it to the main road. This is achieved by arranging that operation of either of these switches associated with the road not having right-of-way provides a demand for relay DE which will cause normal operation of the timing circuit.

In the latest types of controller, the rotary hand control switch is being replaced by lever type telephone switches and the four functions are split between two 2-way switches.

Over-Riding Switch.

In some installations, time switches are provided to switch the signals off during the night hours, and an over-riding switch is incorporated to cut out the time switch in the event of its failure or the necessity for its removal. It is rapidly becoming the practice throughout this country for vehicle-actuated signals to work continuously, and time switches are not generally provided.

Special Facilities, "All Red" Period.

In Part I. of this article, fig. 12 showed a multi-way intersection at which an "all red" phase was necessary. The provision of an "all red" phase is frequently necessary where an intersection is very wide or irregularly shaped, as it will allow the tail of a stream of traffic to be cleared out from the middle of an intersection prior to allowing the conflicting road to be opened. An "all red" period may be arranged so that it follows or precedes one, or any selected change of phase, or every change. For instance, in fig. 12 the "all red" period follows the third phase only, but it will be readily appreciated that under other circumstances an "all red" period might be necessary between every running phase.

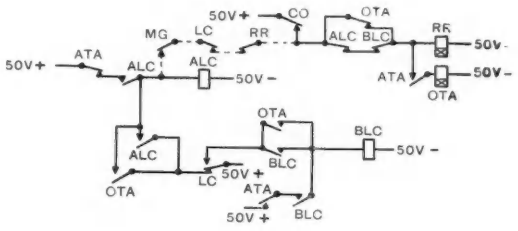
Fig. 11 is a set of four diagrams of an "all red" or, as it is often called, "overlapping red facility" unit. This unit is so arranged that it is in the form of a separate relay set and can be jacked into a standard controller. This relay set contains five additional relays, whose functions are as follows :—

BM which controls the "B" road amber lamps independently of relay AM, as the amber indications have now to be given at different times instead of concurrently.

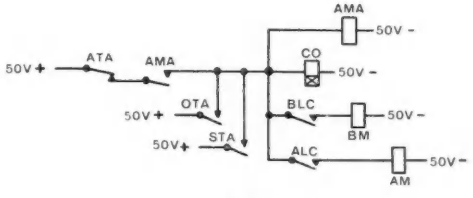
ALC which is normally operated when the "A" road has right-of-way and during the time the amber indication is displayed to "A" road.

BLC which is normally operated when the "B" road has the right-of-way and when the amber signal is displayed to "B" road.

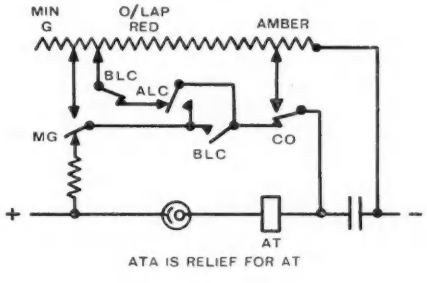
With ALC and BLC both normal, the over-lapping period is measured off.



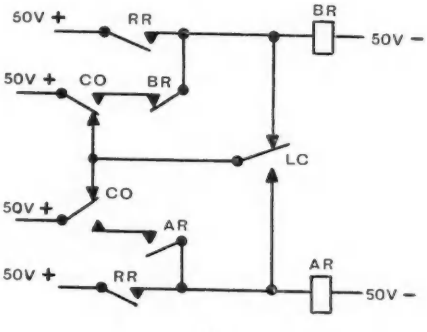
(a)



(b)



(c)



(d)

Fig. 11.—Overlapping red facility circuit.

RR which controls red contactors and operates both together during the over-lapping red period.

OTA which operates at the end of the over-lapping red period to indicate that the second amber period may start.

The circuit operation is as follows :—A circuit is provided for operation of relay ALC (a) when the circuit is first closed *via* contacts MG, LC, RR and CO. These contacts ensure that ALC cannot be operated incorrectly.

Each changeover is initiated by relay STA in the normal manner. Contact STA (b) operates relay AMA, relay CO and the amber contactor relay of the road losing right-of-way. The CO contacts in the road detector circuit function as usual, and a further contact CO connects the amber timer to measure off the first amber period.

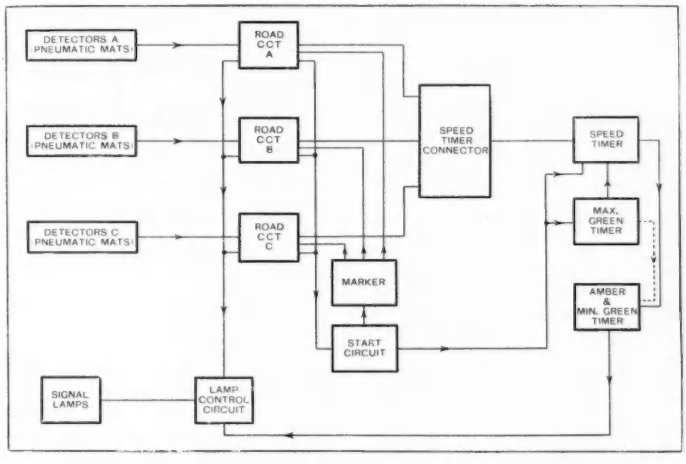


Fig. 12.—Diagrammatic representation of a 3-phase controller.

At the end of the first amber period, relays AT and ATA (c) will operate in the normal manner. Contact ATA (b) will release relay AMA and this will be followed by the release of relays CO and AM or BM, as usual. The amber lamps will be extinguished. Contact ATA will release relay ALC or BLC according to which was operated. Relay CO, being a slow release relay, will prevent operation of relay OTA by contact ATA at this stage. Relays ALC, BLC and CO now being normal, an over-lapping red period will be measured off by the amber timer (*via* contacts BLC, ALC and CO). Relay RR will be operated by contacts CO, ALC and BLC to connect the two red lamp contactor relays.

At the end of the over-lapping red period, relays AT and ATA will operate again on contact ATA operating relay OTA. Relay OTA is locked until the end of the pulse independently of relay ALC or BLC by means of contact OTA. Contact OTA operates relays AMA and CO which are locked by contact AMA. Another contact on relay OTA will operate relay ALC or BLC according to the way contact LC is lying. Whichever relay is operated will be locked by its own contact and the contact on LC. Another contact operates relay AM or BM. The amber indication is now given to the road about to receive right-of-way. Contacts ALC or BLC release relay RR but both red contactors are locked by their own contacts and contacts on CO.

At the end of the second amber period, the amber timer again operates and releases relays AMA, CO and the amber contactor, and from this period the operation of the controller is normal.

If the over-lapping red is required during one changeover only, as discussed earlier, the relevant terminals are strapped to permit relays ALC or BLC to be selected by contact LC as soon as this contact changes over.

Remote Control of the "All Red" Facility.

Under certain circumstances it is necessary for signals to be put to the "all red" indication from a remote location. An example of this is when the signals are in the vicinity of a fire station. This function can easily be carried out when an over-lapping red relay set is installed, as it is only necessary to operate relay RCR from a distant control point to initiate a forced changeover up to the stage of the over-lapping red period and then prevent further change until the control is released. Overlapping red can also be distantly controlled by direct circuits to the lamp contactor relays, but this is not always practicable.

3-PHASE CONTROLLER OPERATION.

Where there are more than two roads at an intersection, it is not always possible to effect satisfactory traffic control with 2-phases, and in such circumstances a 3-phase controller would be used. Generally speaking, it is preferable in multi-way intersections to group as many of the roads as possible in pairs in order to reduce the number of phases and so shorten the waiting periods for roads not having the right-of-way. With such a controller, demands for right-of-way can be treated in two ways—one is known as "first come, first served" and the other as "fixed rotation."

"First Come, First Served" Method.

In the case of lightly loaded roads, a "first come, first served" controller will serve demands in the order in which they are made, which gives rise to the name at the head of this paragraph, although, to some extent, when the roads are heavily loaded the same controller will tend to deal with the demands in alphabetical order. In the 3-phase controller as in the 2-phase, all switching is performed by relays, but the principle of operation is varied slightly in regard to the method of finding which road is making a demand. The principle used in the multi-phase controller is based on the automatic telephone "line finder" system. Each group of roads has a relevant

road circuit containing a demand relay and a lamp control relay. When a road has obtained right-of-way this demand relay is disconnected and its detectors are connected by means of the speed timer connector to the right-of-way relay in the speed timer circuit. All the individual demand relays control a common demand relay. The lamp control relays are so arranged that they can only be operated one at a time, and during energization, or release, relays are arranged to give an amber period to their opposite conditions. A vehicle passing over a detector in a road not having right-of-way, locks up its appropriate demand relay, which will, in turn, operate the common demand relay. A pulse circuit is then started, and pulses are fed into the finder circuit. The road which has registered the demand is marked by the preparation of marker relay circuits and the finder relays search, in order, the marker circuits until the prepared circuit is found. A relay then operates which stops the pulse and finder circuits and prepares a new operating circuit for the speed timer connecting relays, and the striking circuit of the speed timer is also completed. When a changeover takes place, the speed timer relays release the speed timer connector relays, which immediately re-operate, as indicated by the marker relay. The demand relay releases, and the finder and marker circuits then operate again, searching for the next demand. Should vehicles in opposing roads make a simultaneous demand, the controller will deal first with one and then with the other, as not more than one marker relay can be operated at a time. With a "first come, first served" controller, light traffic will, as already described, be treated in the order in which it arrives, but with heavy traffic there is a tendency for the controller to work in alphabetical order. For instance, supposing that the controller is working with roads in the order C, B, A, if the traffic increases on road "B," this road will be arbitrarily interrupted by the maximum timer which will, however, store a demand to revert to "B" when possible. The finder circuit, however, will not start a fresh search until the demand on road "A" has received attention, and as the finder always searches in alphabetical order, it will, of course, come across "B's" stored demand first, and under the circumstances will again proceed to give right-of-way before giving attention to "C." After finishing with "B," "C" will receive attention in spite of the fact that "C" demand may have been registered in the controller before the maximum timer operated for "B" on the previous demand. The controller will then have operated in the following sequence :—B, A B C—in other words, it has now performed a rotation in alphabetical order, but its behaviour after this point will again be subject to the density of traffic in the different roads. The controller will, however, continue to operate in alphabetical order, having once started, as long as two or more of the roads contain sufficient traffic to cause the maximum green timers to operate.

Fig. 12 is an attempt to represent diagrammatically the general principles of a 3-phase controller, and is self-explanatory.

4-PHASE CONTROLLER OPERATION.

The operation of the 4-phase controller is very similar to that of the 3-phase, and the similarity is revealed on an examination of fig. 13. As in the 3-phase controller, a line finder system is adopted—each group of roads having a road circuit containing a separate demand relay. There is also a common demand relay which operates the pulse circuit which, in due course, is connected to the finder circuit. The road which makes the demand is indicated by the marker relay circuit, and the finder relays will search until a prepared circuit is found. From this point onwards the operation of the circuit follows the description already given for the 3-phase controller.

FIXED ROTATION CONTROLLERS.

Although, as previously described, 3 and 4-phase controllers, in certain circumstances, tend to operate in alphabetical order, it is frequently necessary to ensure that a controller will perform its functions in a definite cyclic order. For example, the phase sequence which was illustrated in fig. 12 of Part I. of this article must be adhered to rigidly in order to bring in the over-lapping red period at the end of phase "C," as it is the congestion caused by the traffic left in the intersection at the end of "C's"

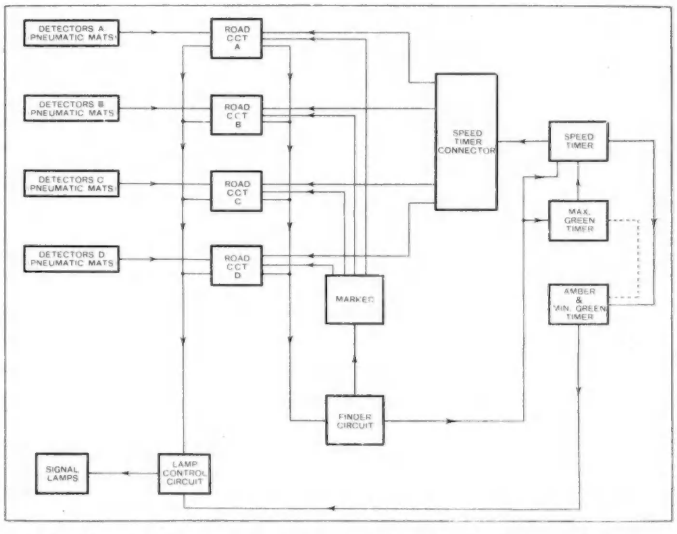


Fig. 13.—Diagrammatic representation of a 4-phase controller.

running phase which must be cleared out before the restarting of phase "A."

In the fixed rotation controller, the finder, marker, speed timer connector and pulse relays, together with the neon timer circuit for pulsing, are replaced by a uni-selector, but the remainder of the operating relays, namely the lamp contactors, right-of-way and demand relays and line relays are retained as in the standard "first come, first served" controller. The adoption of the uni-selector to carry out certain functions slightly modifies the operation of the controller.

It is interesting briefly to follow the sequence of events upon a demand being received. Suppose a demand has been received from one of the roads, the appropriate demand relay will operate and complete the speed timer circuit. As in the 2-phase controller, no further function will take place until such time as the speed timer neon tube strikes. When this tube strikes, the speed timer relief relay will lock up and the uni-selector will proceed to search in alphabetical order starting with the road following that which has the right-of-way. The uni-selector will continue to step until it reaches the first road which shows a demand. The operation of the searching process sounds lengthy, but actually takes place in under 40 milliseconds. When the uni-selector has found the demand, the line relay of the road which is requiring the right-of-way will be operated and a similar line relay in the road losing right-of-way is released. The various road relays and lamp contactors will then be operated in a normal manner. The uni-selector does not make one complete revolution for each cycle. For instance, in a 4-phase controller, four successive steps of the uni-selector will search roads A, B, C and D, and the next four successive steps will again search A, B, C, D. The number of revolutions of the uni-selector in a given time will therefore be dependent on the number of phases and the number of times these can be repeated in the 50 steps of the uni-selector. Actually, in the 3-phase controller one complete revolution would be made every 17 cycles. The life of the uni-selector in these circumstances should be comparable with that of the relays. The over-lapping red facility is provided by leaving a marked contact on the uni-selector immediately following the contact associated with the relevant traffic phase. This marked contact would be associated with a relay which can be multipled to other similar contacts associated with other phase contacts to provide for more than one over-lapping red period, where required.

It is often necessary in multi-phase operation to arrange for the omission of the over-lapping red period in the event of its associated traffic phase not receiving a demand. In such circumstances, the over-lapping red phase is still associated with a marked contact on the uni-selector, but the signal contactors are controlled by the demand relay so that the over-lapping red phase does not come into operation unless the demand relay has been operated. Early cut-off and late release facilities can also be provided for in a similar manner. It should be understood, however, that in some circumstances a relay finder circuit can be designed to operate in a definite fixed rotation and in some cases may be preferable.

The following adjustments are provided as standard on a 3-phase controller :—

Maximum green period adjustment is provided for each road and 10 steps are available, giving a range of timings from 15 – 60 seconds.

Independent minimum green adjustment is provided for each road, having limits of 8 – 25 seconds, and the amber period can be adjusted from 1 – 10 seconds.

As is the case with all vehicle-actuated controllers, the amber period is automatically increased by two seconds when a continuous stream of traffic is interrupted by the functioning of the maximum timer.

With multi-phase controllers, it is usual to provide for hand operation, fixed time operation, switching to all red and a number of other facilities which have been found necessary in practice.

CONTROLLERS FOR INTERLINKING.

Controllers for interlinking must be capable of performing every function which a non-linked controller would perform. In addition, interlinked or local controllers as they are termed, must be capable of being responsive to pulses from a master controller. These pulses (as were described in Part I. of this article) are the indication given by the master controller to each local controller of the requirements of the flexible progressive plan.

The simplest way of describing the sequence of events at a local controller and the manner in which these are co-ordinated by means of a master controller, is by indicating graphically a complete cycle. Fig. 14A represents by means of a circle diagram one complete cycle of operations for a plain intersection, vehicle detectors being provided in all roads. It will be more correct to say that this is a series of circle diagrams, as several circle diagrams are placed concentrically to represent different cycle times. It will be noted that there are two pulse positions, and these represent the pulses in time relationship as received from the master controller. Their position relative to one another can be varied. The general practice is to locate the facilities for setting the relative positions of pulses A and B in the master controller. However, for the moment the method of setting up the pulses can be ignored. Pulse A, when received from the master

controller, represents the start of the cycle of events at the local controller. Immediately on receipt of pulse A, the local controller will measure off the prevent period. This prevent period, as previously described, is to stop transfer of right-of-way to the side road at a time when the main road stream is about to be released. As soon as the prevent period timer has completed its function, what is known as the A privilege period is timed, and during this period the A, or main road traffic, has unrestricted right-of-way so long as demands are made by traffic passing over A road vehicle detectors.

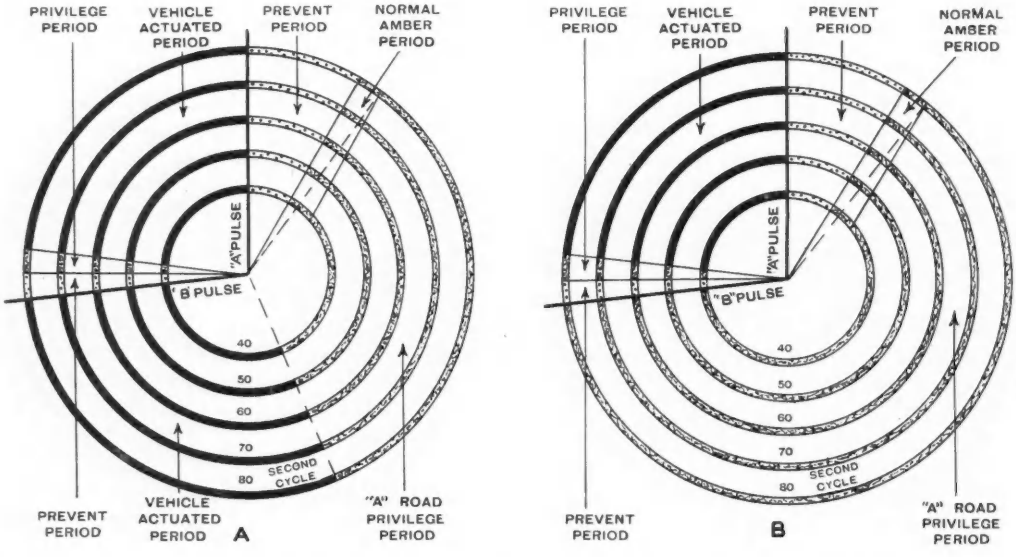


Fig. 14.—Progressive operation of local controller with (A) detector mats in all roads and (B) detector mats in side roads only.

This privilege period is usually made sufficiently long to enable the main road traffic flow to be established in both directions and so cover any gap which may occur between the two main road streams. This gap may be caused by the fact that, although green is showing in both directions on the A road, traffic may arrive from the previous intersection in one direction earlier than from the previous intersection in the other. If the gap in time between the arrival of the two streams were not protected in some manner, the arrival of vehicles in the side road during the gap would produce an immediate vehicle-actuated change with resulting disorganization to the main road traffic flow.

On the termination of the A road privilege period, the A road vehicle-actuated period commences, and this period—which is not timed—is limited by the arrival of the B pulse. During the vehicle-actuated period, there is no preference given to the A or main road traffic, which can be broken into by a demand from B road should a gap occur in the main road flow. Such a gap would be indicated by the striking of the speed timer, as is shown in the elementary 2-phase description. The arrival of B pulse starts a similar series of events for the B or side road, and this sequence is again terminated by the arrival of pulse A and the start of a new cycle. The position of these pulses is indicated on the sample flexible progressive diagram illustrated in fig. 18 in Part I. of this article. There are, however, many installations in which vehicle detectors are provided in the side roads only, and under such conditions the circle diagram in fig. 14A is not suitable and the diagram in fig. 14B should be employed. This diagram has been laid out on the same principle, and, as before, two pulses A and B are received from the master controller. Pulse A initiates the prevent period, followed in due course by the A road privilege period. In this case, however, the A road privilege period lasts until the arrival of pulse B. It is clear that this is necessary, as there are no vehicle detectors in the through road to provide a controller with the means of ascertaining when gaps occur in main road traffic flow. On receipt of pulse B, the B road prevent and privilege periods are started, which are followed by a B road vehicle-actuated period.

It is evident that this method of operation gives preference to the main road traffic and the band width laid out on the diagram for main road traffic represents the shortest green time on the main road. This green time cannot be diminished, but it may be extended in the absence of traffic in the side road. For main thoroughfares which are heavily loaded, this system offers certain advantages from the traffic point of view, quite apart from the saving in a number of vehicle detectors.

There are some 60 intersections in London operating on this "2-mat" system.

It must not by any means be assumed that the 2-mat system is satisfactory for use whenever interlinking of controllers is adopted, because, in many installations operating on the Autoflex progressive system, the side road traffic is sufficiently important to warrant its receiving almost the same consideration as the main road traffic.

It is essential that the prevent and privilege periods, once having been set up, should maintain a definite relationship with the total cycle time; in other words, as the cycle time is decreased these periods should decrease proportionately. It is therefore necessary for the master controller to indicate to each controller the length of cycle time. This is achieved by arranging for the pulses transmitted by the master to have a length which bears a definite relationship to the cycle time. The timers at the local controllers will then bear a definite relationship to the pulse length. In practice, the prevent and privilege periods are adjusted at the local controller with the master set to give a definite time cycle.

It is usual, when setting up the timers on an interlinked or co-ordinated system, to set the master controller cycle at the cycle time indicated on the flexible progressive diagram. The prevent and privilege periods are then adjusted to meet the traffic requirements on the basis of this cycle. Having been so adjusted throughout the system, they will then automatically vary in proportion to the total cycle whenever this is adjusted at the master controller.

BRIEF DESCRIPTION OF OPERATION OF INTERLINKING CIRCUIT.

The pulses from the master controller are received on a shunt field relay. The polarizing winding is reversed after each pulse so that only alternate positive and negative pulses can be accepted by the controller. This forms a means of bringing the controller into phase within one cycle of its being switched on. The durations of the prevent and privilege periods are determined by the charging of two condensers simultaneously for the duration of each pulse—pulse duration varying with the cycle time, as already described. These two condensers are then discharged in succession in a neon tube timer discharge circuit.

When it is necessary to initiate a change as required by the progressive control, the circuits of the maximum green and speed timers are completed simultaneously, but the maximum green timer is arranged so that it does not operate until a short period, approximately half-a-second, afterwards. This is to ensure that the extended amber is not given if the speed timer is able to operate at once under the conditions of no arbitrary interruption to traffic, and also to avoid unnecessary reversion to the road from which right-of-way is being taken.

"A" Road Prevent Period.

During the prevent period, if A road has right-of-way, demands from the B road are prevented from being effective because the B road detectors are disconnected from the DE relay and are connected *via* various circuits to a further relay which receives the demands from B road. If, however, B road already has the right-of-way at the beginning of the prevent period, this right-of-way may be extended by the B road traffic in the normal manner. In such circumstances demands from A road during this period would operate the demand relay. At the end of the prevent period the appropriate timing circuit operates.

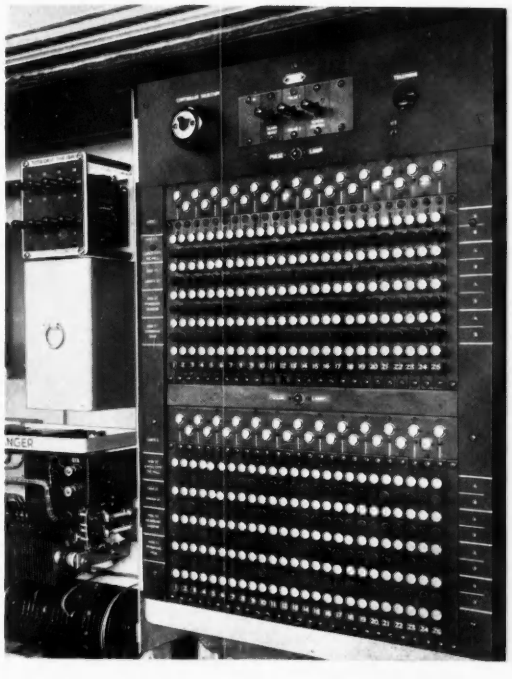


Fig. 15.—Pulse-setting switch panel at a master controller.

"A" Road Privilege Period.

If A road has right-of-way at the beginning of the prevent period, no transfer of right-of-way will occur, but if the B road was in possession of right-of-way at the beginning of the prevent period and had kept it because there was no traffic in A road to take it away or because there was continuous traffic in B road, then a forced change of right-of-way would not take place until a demand is made by the A road. The A road privilege period is now measured off, and at the end of the privilege period the timer circuit will strike.

"A" Road Vehicle-Actuated Period.

During the A road vehicle-actuated period, the controller is fully vehicle-actuated but with preference for the A road, and should there be a stored B demand, change of right-of-way to B road may take place in the absence of continuous traffic on the A road. Should, however, an A road demand be received immediately, right-of-way will again revert to the A road as soon as the B road minimum green expires—this change being initiated by means of a maximum green forced change circuit.

"B" Road Periods.

A similar sequence of events takes place on a changeover to B road, with the exception that the

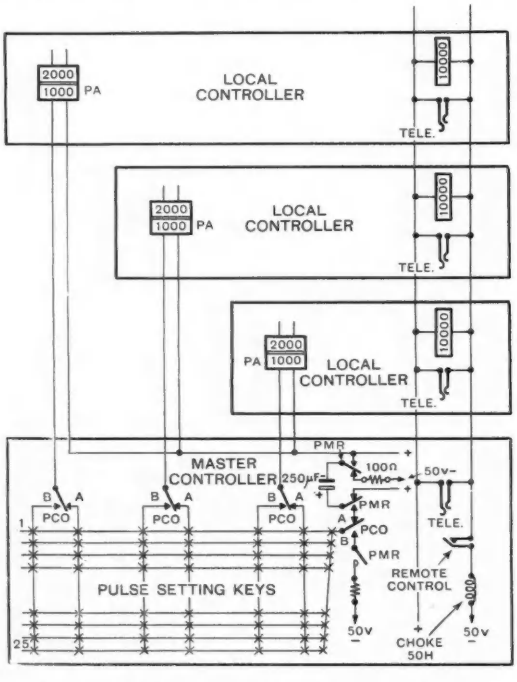


Fig. 16.—Diagram showing circuit principles of interlinking scheme.

B timing resistances are selected. Where no detectors are provided in the A road, the A road detector terminals are strapped by a resistance which simulates a permanent demand in the A road.

Facilities Provided with Interlinked Controllers for Co-ordinated Working.

It is usual with local controllers to provide all the facilities which are available for use with controllers for isolated working. Additional 10-step switches are provided for the adjustment of the prevent and privilege periods for both A and B roads where there are detectors in all roads, and for the B road only where there are no A road detectors. As these periods vary proportionately with the cycle time, the dial plates are calibrated with letters in place of the actual periods which are used with normal timers.

MASTER CONTROLLERS.

Functions to be Performed.

The main requirements of a master controller are to measure the cycle time and indicate this cycle time to all the local controllers, and to measure off the correct position of the A and B pulses for each of the local controllers. The master controller must, in addition, indicate to the local controllers the duration of the prevent and privilege periods for each road. These periods should bear a definite relationship to the cycle time, and the controller must be capable of performing this adjustment of the various periods automatically when the cycle time is adjusted. It must also be possible for the cycle time at the master controller to be capable of adjustment by means of a traffic integrator.

Brief Details of Method of Operation.

The measurement of the total cycle time is carried out by means of a neon tube timer which feeds into either a relay counting circuit or a uni-selector, according to the type of master controller in use. The cycle time can be varied between the limits of 30 and 120 seconds.

With the relay type of counting circuit, the master cycle is divided into 25 divisions, and in the case of the uni-selector type, into 50 divisions. Each of these 50 divisions is represented by a pulse from the timing circuit. In order that any one of the 25 or 50 pulse positions can be selected for each local controller, they are all multipled to a series of switches or plugs—an appropriate number being provided in the master controller. In the case illustrated in fig. 15 the name of the intersection will be seen alongside a double row of such push-pull switches. The top row of the double row represents the A pulses, and the bottom row the B pulses. The A pulses are all positive pulses, and the bottom row or B pulses are negative. The negative pulses are sent direct to line from the transrecter by means of the impulsing relay, but the positive pulses are obtained by discharging an electrolytic condenser into the line.

In order to give an indication of the various period lengths to the local controllers, the pulses are arranged to vary in length in relation to the cycle time and a separate outgoing pulse timer is used for this purpose. The two timers, that is to say, the master cycle timer and the pulse timer operate in sequence—the master timer initiating the pulse at the termination of each of the 25 or 50 spaces, and the latter terminating each pulse after its correct duration.

The master cycle timer is also used to operate a relay selector circuit to connect the pulse circuits to the outgoing lines at the appropriate parts of the

cycle. The pulses are received at the local controllers on groups of condensers which are charged in parallel and then discharged in sequence, and arrangements are made so that the transmitted impulses neutralize the effects of the hyperbolic charge and discharge curve of the condensers at the local controllers.

Fig. 16 is a skeleton circuit which shows the circuit principles of the interlinking scheme, and it will be noticed from this that telephone facilities are available over the remote control line which is provided for switching the system on and off.

Dual Masters and Alarm Circuits.

It is the general practice to provide master controllers in duplicate with automatic changeover switches to effect a change to the spare master in the event of failure. A time switch is also provided which, each day, reverses the spare and working masters in order that the spare shall always be kept in an operating condition.

The alarm circuits are arranged so that they effect the changeover to the spare master under the following conditions :—

1. When there is a complete pulse failure.
2. A pulse of too long a duration.
3. A pulse sent out on a disconnected line.
4. A failure of the power supply.

The alarm circuits are fed from the power unit of the spare master, and alarm lamps are provided to give an indication of failure. In the case of certain installations in this country, indication of failure is provided in the nearest police headquarters.

Automatic Phase Change.

The latest development is the provision of master controllers with pulse setting panels in duplicate. One panel may be set up for 2-phase control, and the other for 3-phase, and arrangements made for an automatic change from one panel to the other by time switch at specified times of the day, or automatically by integrator at a certain traffic density. In these circumstances, local controllers giving the maximum number of phases are provided at each intersection, and phases are connected in parallel to eliminate the unwanted traffic phase on a conversion, for instance, from 3 to 2-phase. The control of conversion at the local controller is carried out over a special line wire energized at the same time as the master changeover takes place.

Fig. 17.—Front and rear views of typical controller.

TRAFFIC INTEGRATORS.

General Principles.

Traffic integrator is the name given to a device which has been designed primarily to provide an automatically varying cycle time at the master controller to suit varying volumes of traffic. In its simplest form the traffic integrator consists of a device which adds up the total number of impulses received from the detector pads provided in all the roads at a representative or important intersection in the system. If the summation of these impulses varies from a previous summation, then the cycle time is adjusted accordingly. The traffic speed, as planned on the time-distance diagram, is inversely proportional to the cycle time, and the traffic

integrator, under such conditions, will give an increasing cycle time and a fall in the rate of travel for increasing traffic.

Further Consideration of Traffic Requirements.

In Part I. of this article, curves were reproduced[2] showing the performance required of a traffic integrator, and a description of its behaviour was given.

It is useful to give a brief reference to the formula which gives the relationship between the volume of traffic and the cycle time. The formula which has been used as a basis in the design of traffic integrators so far manufactured is due to Adams, and is as follows :—

$$C = \frac{2a}{1 - \frac{2T}{L5}}$$

where

C = Minimum practicable cycle time in seconds.

a = Loss of time in starting up at each change-over, in seconds. This may be assumed to be approximately 16 seconds, including an amber period.

T = The total traffic at the intersection in vehicles per hour.

L = Total number of traffic lanes at the intersection.

S = Saturation traffic density per lane. A lane is completely saturated when the traffic intensity is approximately 1,800 vehicles per hour.

This formula was produced as a result of observations made on isolated crossings, and its application to progressive systems has given satisfactory results up-to-date.

Values of T for different integrator settings are taken from actual traffic counts made at the key crossing, by means of vehicle detectors in conjunction with an automatic recorder.

In designing the traffic integrator, some attention has to be paid to the limits over which the cycle time shall be varied. With an integrator of standard design, 37 cycle times are available, but it is rarely necessary to utilize the whole range. In any case, the upper limit of cycle time is indirectly set by the legal speed limit of 30 miles an hour. The lower limit is largely empirical.

Circuit of a Traffic Integrator.

The circuit functions of the traffic integrator can be divided into four sections :—

1. The timing circuit, to measure off the initial times for the periodic counts.
2. A circuit for performing the actual counting of detector impulses.
3. A circuit for the control of the master cycle.
4. A duplicate circuit to maintain the cycle time settings while the master cycle control circuit is preparing a readjustment of cycle time.

Timer circuit No. 1 is a normal timing circuit, as previously described, arranged to measure one minute periods. This timing circuit feeds into a relay counting circuit which completes its function after five impulses, representing that five minutes have been received from the timer.

The circuit referred to in 2 is interesting, as provision is made for reducing all impulses received from vehicle detectors to a standardized length. This is achieved with two relays—one fast, and one very fast. A neon tube and condenser circuit is provided, which is arranged to strike on receipt of a given number of impulses, and a uni-selector is provided as a means of recording the number of operations of the timer circuit. The sequence of events in the operation is easily understood by the following explanation. Each impulse from the vehicle detectors represents an axle. The impulse is reduced to a standard length and each impulse discharges a condenser by a given amount. As soon as the pre-determined number of axles has discharged the condenser to the striking point of the neon tube, the neon tube strikes and the impulse caused by the striking of the neon tube steps the uni-selector one step ; thus, if the timer circuit is set to strike after every 20 axles, each step on the uni-selector will represent a count of 20 axles, therefore, when the arm of the uni-selector is in the 25th position, 500 axles will be the total count.

The circuit for the control of the master cycle consists of a complete set of timing resistances and a uni-selector arranged to select a resistance appropriate to the master cycle time required. This switch is arranged to take up the same position as the uni-selector in circuit 2.

The duplicate setting switch is another uni-selector, which also preserves the same setting as the switch in 3, and holds the cycle time while the master cycle setting switch is taking up a new position.

Adjustments Provided in Traffic Integrator.

A setting field, consisting of a large number of terminal tags which can be strapped as required, is provided to enable the increments or decrements of the master cycle to follow a given curve.

An adjustment in the form of a continuously variable resistance is provided for adjusting the number of axles which may be counted for each step of the counting uni-selector.

A switch key is provided to enable the vehicle detectors to be cut out, and a further switch is available enabling a manual count to be made to

2. "G.E.C. Journal," Vol. VII., No. 3, p. 211.

check the setting of the neon tube timer and setting switch.

General.

The traffic integrator is usually mounted as an integral part of its master controller, and when master controllers are provided in duplicate, it is usual to provide duplicate integrators and power units.

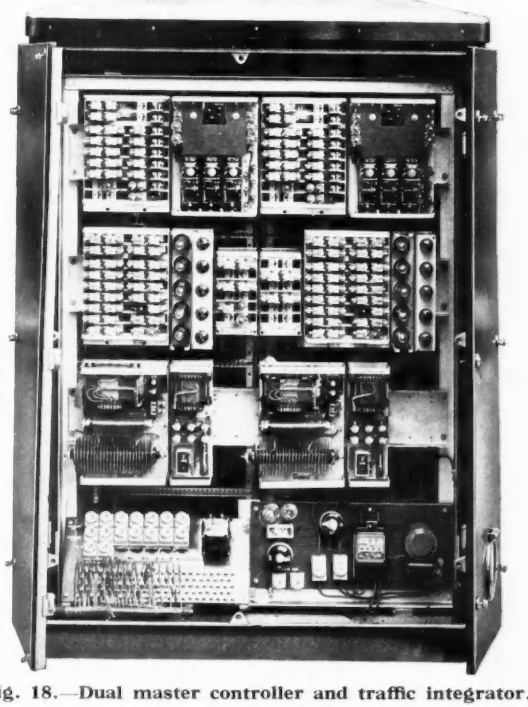


Fig. 18.—Dual master controller and traffic integrator.

Fig. 18 is an illustration of a complete duplicate master controller. The top two demountable units represent the integrator counting switches and relays. Below is a master controller relay unit and a neon tube unit. These are duplicated on either side of the centre line and situated between the two are the changeover relay sets. Underneath are the four power units, two for the master controllers and a separate pair for the integrators. A fuse and terminal panel is provided in the base of the kiosk, together with a main switch and fuse panel on which is mounted the daily changeover time switch provided for the purpose of changing over the operating and spare master periodically so that both are given equal periods of service.

CONCLUSION.

The main features of the Autoflex system have been briefly outlined, together with the circuit of the 2-phase controller, to enable an idea of the underlying principles of operation to be understood. The information given, however, does not cover the design of special controllers which have been developed to meet unusual circumstances.

Some extremely interesting controllers have been designed incorporating :—

Early cut-offs.
Late releases.
Conditional overlapping red periods.
Consequent ambers.
Automatic conversion of isolated controllers from one method of traffic phasing to another.
Single line bridge schemes.
Speed timed overlapping red periods.
Red suppression units for use when there has been a lull in traffic.
Facilities for pedestrians,

and numberless other special devices.

There is, at the present time, no comprehensive work on traffic control by automatic devices, and the author regrets that he is unable to give references to works describing methods of control adopted in other countries, but it can safely be said that Great Britain is well ahead of any other country with regard to the automatic control of road traffic.

Some Technical Aspects of Architectural Lighting.

By R. O. Ackerley, Manager, G.E.C. Illuminating Engineering Dept.
and E. H. Penwarden, Chief of Fittings Design Office of the G.E.C.

INTRODUCTORY.

TWO main factors have influenced the technique and practice of decorative lighting and in recent years brought about a very radical change in outlook. The first of these is the increased demand on the part of the public for artificial light as a useful commodity, which not only increases visibility but also provides that atmosphere of cheerfulness and brightness which is needed to counteract the effects of the strain of modern life. Until recently the architect or decorative designer considered lighting fittings solely from the decorative point of view, with the result that in the vast majority of cases the illumination which they provided was either insufficient, or badly distributed, with a tendency to excessive brightness or glare on the one hand, and dimness and shadow on the other. To-day such lighting fittings may still be found, but their use is fast decreasing and the modern designer realises that fittings must be not only of attractive appearance but in addition ensure a generous amount of light.

The second factor referred to is the introduction of what is usually described as architectural lighting. This form of lighting is to a great extent a natural sequence of the demand for more light, because of the impossibility of giving more light from fittings of the old type without increasing the surface brightness of individual units to such a degree that they became glaring. Consequently it was necessary to increase the size of luminous sources, and the large luminous or illuminated surfaces which are a feature of architectural lighting are a natural corollary. Due tribute must however be paid to the very considerable advance in our knowledge of decorative media in their relation to lighting, and particularly the advance in the technique of manufacturing glassware for illumination purposes which made these developments possible. The result is that to-day the illumination values demanded are continually increasing, and in so far as the criterion of lighting values is largely a matter of contrast and custom, installations which a few years ago would have been considered light and cheerful are now regarded as dim and depressing.

In considering some of the technical aspects of decorative lighting, it is proposed to limit the scope of this article mainly to considerations which arise

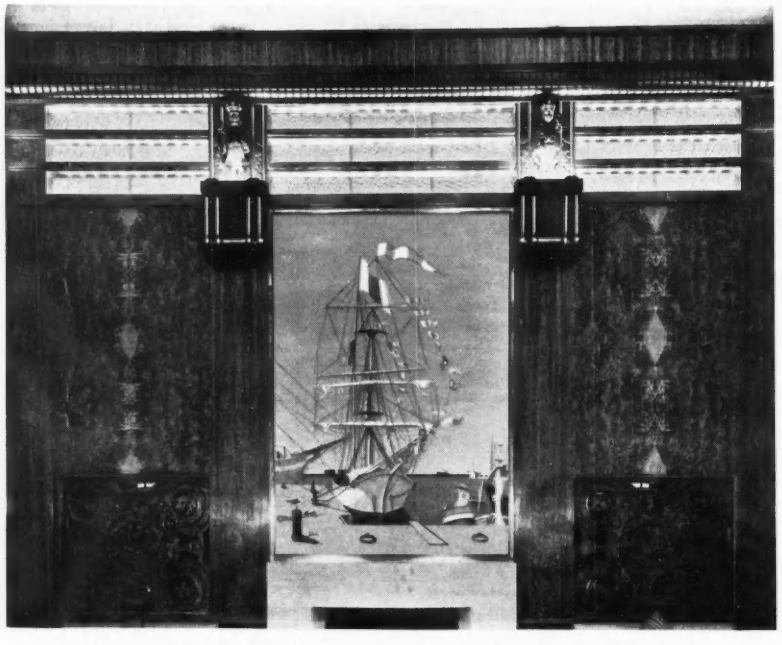


Fig. 1.—Example showing how specular reflections can be made to harmonize with the decoration motif. *(See also fig. 9.)*

from the use of architectural lighting. For purposes of clarity architectural lighting may be defined as embracing systems of lighting which utilize luminous or illuminated surfaces as an essential part of the design of a room, and where the requisite lighting equipment is either built in or on the structure as an integral part thereof. Obviously, however, many of the basic laws applying to this class of lighting will apply equally to all forms of decorative lighting.

THE FUNCTION OF THE ILLUMINATING ENGINEER IN DECORATIVE LIGHTING.

Since artificial light costs money, the demand for increased illumination values obviously means that the question of the lighting efficiency of fittings assumes greater importance, while the necessity for distributing the light advantageously so as to avoid glare on the one hand and excessive diversity on the other calls for a practical knowledge of the laws and technique of light control. It is for this reason that the necessity arises to make full use of the science of illumination, and successful and effective modern lighting can only be attained by close co-operation between the illuminating engineer and the decorative designer. In the past there has been a difficulty in reconciling their respective points of view, for the artist tends to claim freedom from laws in order that he may develop his creations in conformity with his personal conceptions. On the other hand, the scientist's procedure is based upon a recognition of the existence of hard and fast natural laws; thus the essential relationship between the two is liable to be overlooked. This relationship is that science must ever be the servant of art, and the more the artist appreciates and makes use of his servant the simpler will be his task.

This is particularly true in the world of decoration, where almost daily new materials are being evolved by the scientist as media on which the decorator may exercise his skill, but in order that the best results may be obtained a true appreciation of the possibilities of the medium in which he is working must first be obtained. Not least important among these new media must be placed the development in the design of electric lamps and lighting equipment, and however much the decorator, wishing to embody lighting as part of his decorative scheme, may claim freedom to create his own conception, he must be bound by the natural laws which control the distribution of the light from the artificial or natural light source that he is employing. It is the function of the illuminating engineer to advise the decorator on these points; to help him by the design of suitable controlling equipment, or other means, to achieve the artistic effect he desires.

A fruitful source of misunderstanding between artist and engineer lies in the tendency for the latter to have a preconceived notion as to what is good and bad lighting, a notion which does not necessarily coincide with that of the artist. It may be helpful to examine the cause of this misunderstanding which lies at the root of their difficulty in each appreciating

Fig. 2.—An example of the effect of proper planning of the lighting system. The illustration on the left shows patchy cornice illumination and heavy shadows on the decorated ceiling and walls. In the illustration on the right these faults have been eliminated.

the other's point of view. If a bare lamp be placed in a room it will throw out light in all directions and the nearer any particular object is to the light, the brighter it will be. For most practical, as distinct from decorative purposes, (for example, in an office, factory or kitchen), objects do not need to be illuminated to greatly varying degrees of brightness, but it is desirable to control the available light rays so that every object in the room is lit more or less to the same brightness. Consequently, the illuminating engineer's activities have been occupied largely with the problem of taking a light which naturally would illuminate a given area unevenly and controlling it so that it spreads its light evenly. For this reason the engineer is liable to assume that evenness of lighting is the criterion of good lighting; consequently, if he has to light a laylight panel or a ceiling cove, for example, he is very prone to light it as evenly as possible.

The decorative artist on the other hand, may contend that evenness of illumination is apt to become monotonous, or to kill the beauty of mouldings and architectural features. He wants gradual or sudden changes of light intensity and falls back on the uncontrolled or badly controlled light, which he knows will give him the necessary variety even if he does not obtain it exactly as he wants it. But the artist should realize that the engineer can be employed to create shadows as well as remove them, and the engineer should appreciate that evenness of illumination is not the sole consideration.

There is thus raised the question as to how the illuminating engineer can be of assistance to the artist. In order to be in a position to answer this question accurately, it is necessary to examine exactly what is meant by illuminating engineering. As a first step, it must be recognized that the emission of light from any source is governed by certain natural laws, the most important being, first, that without interference, the light will radiate equally in all directions, and, secondly, that the intensity of light on any given surface varies as the square of the distance of that surface from the light source.

In practice, when dealing with artificial light, these laws may be rather inconvenient because in the first place—as mentioned above—its production costs money and all the light emitted has to be paid for whether it is radiated in a direction where it is useful or not; and secondly, for physical and financial reasons the number of artificial light sources in any room must be limited, and it may not be at all suitable that the illumination at a point six feet from one light is only 1/36th of that one foot away from it, as, for instance, would be the case on the ceiling, illustrated in fig. 3, at points C and D if the light source at A were uncontrolled.

This is where the illuminating engineer must be consulted, for the distribution of light from a light source, while naturally tending to obey this law of equal distribution in all directions, can be controlled by various means so that rays of light, which are radiating in directions where they serve no useful purpose, can be caught and turned in directions where they can be usefully employed, and if necessary can be used so as partially or entirely to counteract any disabilities due to the law of inverse squares. For example, again referring to fig. 3, if sufficient of the light emitted outside the angle CAF can be thrown towards the point D so that there is thirty-six times as much light going in this direction as there was previously, the intensity

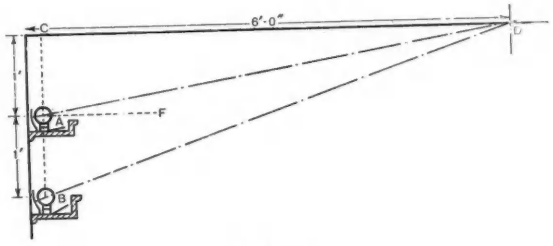


Fig. 3.

at point D will now be as great as that at point C, assuming that at the same time no extra light has been sent towards C. One of the methods of controlling light is well known, namely, the use of a reflector, and it may appear a simple matter to solve the problem by the utilization of a reflector; but it is only by designing the reflector in a certain way, curving it to a certain predetermined contour, regulating its overall size and so on, that a known proportion of light can be directed in any one direction. Moreover, the problem is very much more complicated by the fact that when using ordinary electric lamps the light comes, not from one point but from quite a large area, and in the process of reflecting one portion of the light towards D, another portion may be reflected inadvertently towards C thereby nullifying the attempt to adjust the relative brightness.

It has been assumed in this example that equal brightness at points C and D is required, but obviously, if sufficient light for this purpose can be re-directed by correct design of the reflector, any intermediate stage of adjustment may be attained, *i.e.*, if a gradual falling off in light is required, it can be arranged that D is half or one-fourth as light as C, according to requirements.

If real point sources of light were under consideration, *i.e.*, within Euclid's definition of a point as having position but no magnitude, almost any desired relative light distribution could be obtained, but owing to the fact that the illuminating engineer's ideal of a source of light of no magnitude and infinite brilliance is not attainable, it is necessary

to make the best of the limitations imposed by the size of the light sources, and these limitations have a direct bearing on the degree to which it is possible to control the light distribution and the physical dimensions of the equipment needed to do it. This in turn has a direct bearing on one of the biggest sources of contention between illuminating engineers and decorative designers, namely, the space that

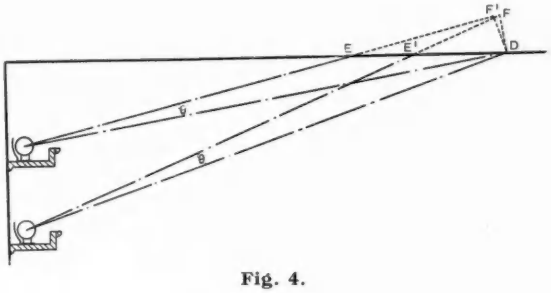


Fig. 4.

must be left for concealing lighting equipment in cornices, recessed panels and similar decorative lighting devices. Examination, therefore, of a few typical examples may be of interest.

There are two directions in which space is liable to be unduly limited, the first and commonest being the allowance of insufficient offset to permit of reasonably even illumination over the area to be covered, whilst the second is failure to provide sufficient room for the housing and concealment of the actual reflectors or other controlling equipment.

Considering the question of offset first, an example taken may be of the case of a straightforward installation of indirect lighting from the cornice, illustrated in fig. 3.

It is assumed that the cornice reflector is located at position A one foot below the ceiling level, and that the width of the room is 12ft. so that the centre line of the ceiling running through D is 6ft. out. Then as the distance from A to D is approximately six times as great as the distance from A to C, thirty-six times the amount of light that reaches C must be directed towards D to obtain even illumination. If the cornice is now considered as being 2ft. below the ceiling the relation of BC to BD becomes about 1 : 3 instead of 1 : 6, and only nine times the amount of light is required in the direction BD to obtain even illumination. It is obvious that it is far easier to achieve the latter object than the former.

Even on the above basis a part of the disability due to the limited offset at A has been considered, for there is a further disability due to the oblique angle at which the light strikes the surface of the ceiling, the required intensity of projection towards any surface which the light strikes at an angle being increased in proportion to the cosine of the angle of incidence. This is illustrated in fig. 4, where it is shown that the area to be illuminated by the light emitted over a given angle θ is increased in the proportion of the length DE to the length DF if the light strikes the surface at an oblique angle instead of normal to it.

Fig. 4 also indicates that the greater offset decreases this disability because the ratio of DE_1 to DF_1 is far less than that of DE to DF. This provides a typical example of how offset affects illumination, and clearly the same argument applies in the case of a recessed wall motif, or where it is desired, instead of reflecting off a surface, to transmit light evenly through a translucent medium such as a glass panel. In the latter case, however, questions of internal reflection also arise. This is illustrated in fig. 5, where the curve indicates how the amount of light specularly reflected off a clear glass surface increases as the angle of incidence of the light becomes more oblique, so that the advantage of an adequate offset enabling the light to be directed

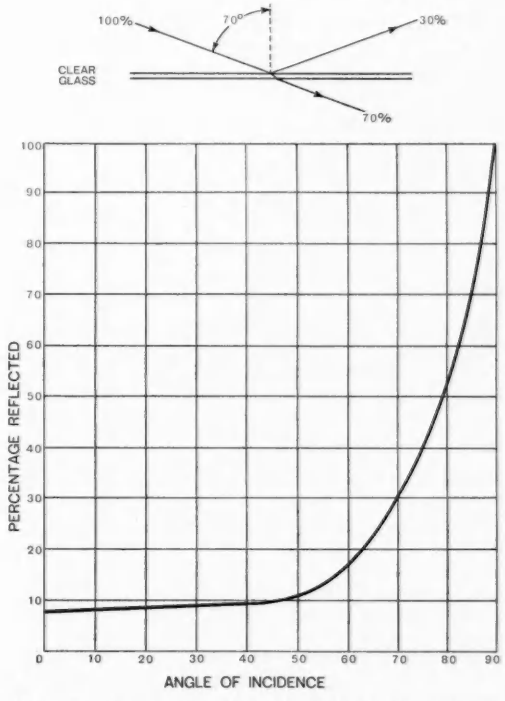


Fig. 5.—Curve showing percentage of specular reflection of light off clear glass at various angles of incidence.

on to the glass surface as nearly as possible to the normal becomes correspondingly greater.

The question of what is adequate space for the actual housing of the light controlling equipment is influenced mainly by two considerations. The first is the need for the inclusion of the biggest possible angle of light within the orbit of control. (*i.e.*, it is

obviously advantageous to redirect usefully as much as possible of the light which would otherwise be wasted) ; and the second, the fact that the maximum amount of light which can be redirected towards any point bears a direct relationship to the projected area of the reflector in that direction. Reference to diagram 6 will illustrate this.

Assuming that all the light within the angle ϕ would be wasted unless controlled, then clearly a reflector covering the arc AX would control more light than one covering the arc AY as, owing to the bigger angle, more light initially strikes the reflector. If it be assumed that P is the point to which it is desired to direct that waste light, the increase in light flux which strikes the reflector does not help matters at all as it cannot be re-directed in the right way, the projected area actually remaining the same. If, however, the reflector is opened out to Z without embracing any more light flux

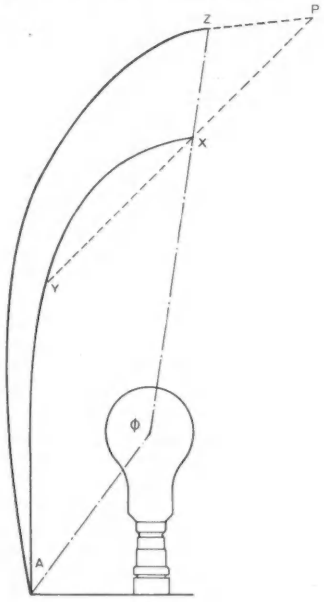


Fig. 6.

(*i.e.*, it is still collecting light over the angle ϕ and no more), light may be re-directed from this whole reflector towards P.

This problem of space is intimately bound up with the question of sight line, *i.e.*, with the problem of concealing the lamps and reflecting material out of sight. Diagrams 7 and 8 show how in a cornice lighting system, similar to that already used to illustrate offset difficulties, the overall projection of the cornice affects the degree of control that can be exercised. Assuming a sight line SL, below which all equipment must be kept to be invisible, the reflector MN can embrace a reasonable light flux and the whole reflector is open to the point X, towards which it is desired to redirect the greatest amount of light. If now it is desired to increase the size of the reflector to embrace more flux this may be accomplished by increasing the height of the front lip AB (fig. 7) so that it becomes as A_1B_1 (fig. 8), thereby allowing more reflector NQ at the back, but in the process there is cut off from X that part of the light which reached it from the section MP. If, instead of increasing the

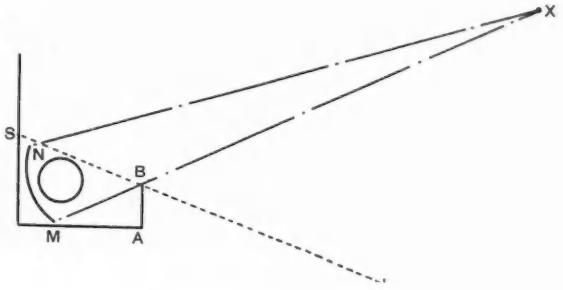


Fig. 7.

height of the front lip, the projection of the cornice from the wall is increased so that AB now takes the position A_2B_2, not only is all the extra flux obtained at NQ as well as that at MP, but light from the whole reflector can now reach the point X.

It will thus be seen that provision of extra space materially simplifies the problem. While in all these examples one point of the ceiling has been dealt with, the argument applies progressively to all the area from the wall to centre of the ceiling, and

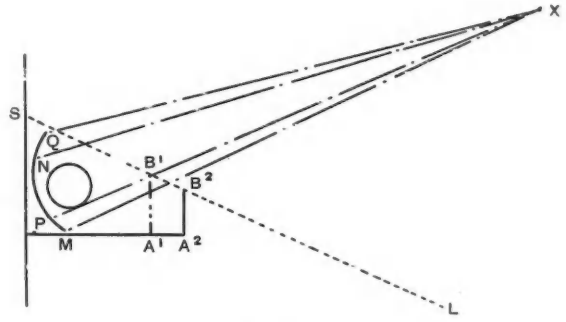


Fig. 8.

while a cornice lighting example has been selected for the sake of simplicity, parallel situations arise in almost every form of built-in lighting.

Before considering some of the questions connected with the construction of architectural lighting units and the materials used therein, mention should be made of one device in common use which has a direct bearing on light control from the aspect both of efficiency and distribution. This device is the employment of curved backgrounds with the idea

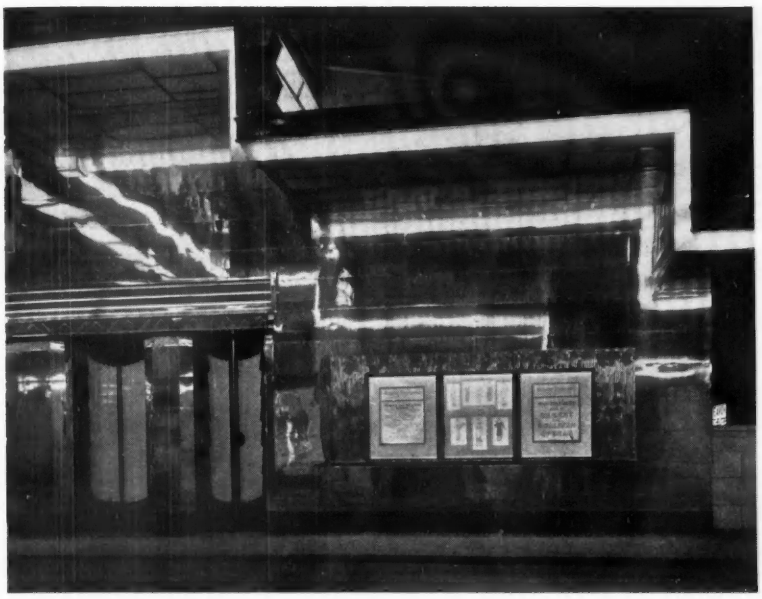


Fig. 9.—Unforeseen specular reflections spoil the effect of this scheme (see also fig. 1).

either of adding to the amount of light flux usefully employed or making the illumination more even. Reference to figs. 10 and 11 illustrates these two applications. Fig. 10 represents the section through a wall panel or through a laylight indirectly illuminated from one edge. An examination of the amount of light projected on to the background and thence reflected on to the glazed panel, shows that in that half which is furthest away from the light source, by curving the background the amount of light flux usefully employed is increased in the proportion of 26 to 12. This not only increases the efficiency but reduces the contrast between the brightness of the section nearest the lamp and that furthest away.

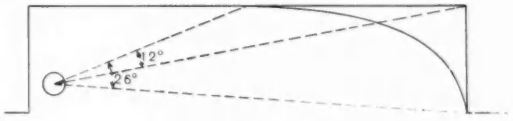


Fig. 10.

Fig. 11 may be considered as representing a cornice with ceiling above ; it will be seen that with the wall going straight up at right angles to the ceiling there will inevitably be a sudden variation between the brightness of the edge of the ceiling and the top of the wall, the amount of illumination striking an equally wide band of each being in the proportion of the angle β to the angle α *i.e.*, 15 to 4. If, however, a curved cove of suitable contour be provided it will be found possible to grade the change in illumination so that it is practically unnoticeable, *e.g.*, a length of arc equal to that illuminated by light within the angle β is now lit by that from the angle γ, *i.e.*, a ratio of 15 : 20 instead of 15 : 4.

This question of reflecting backgrounds logically brings us to the consideration of the nature of the surface forming such background. To ensure maximum overall efficiency all backgrounds should naturally be of as high reflection factor as possible, but it is not generally realized that the reflection factor of a matt white surface such as really matt white paint or even vitreous enamel may be as high, or higher, than that from a specular reflector such as polished metal. Such a matt reflector has also the very great advantage that, independently of the direction from which the reflected light originally came on to it, the amount of light reflected from it in any direction is proportional to the projected area in that direction, and consequently, by suitable design it may be ensured that as much light as possible comes off the reflector in any required direction, independently of the original source. In the case of a specular reflector this rule does not apply and the direction at which any beam of light comes off the reflector is in direct relation to the angle at which it comes on to it. In the case of a background to an enclosed fitting, there has to be taken into account not only the reflection of light deliberately thrown on to it but, in addition, all stray light reflected off all the sides including the front of the fitting. This means that light may be striking any one part of the background from half a dozen directions simultaneously and a specular

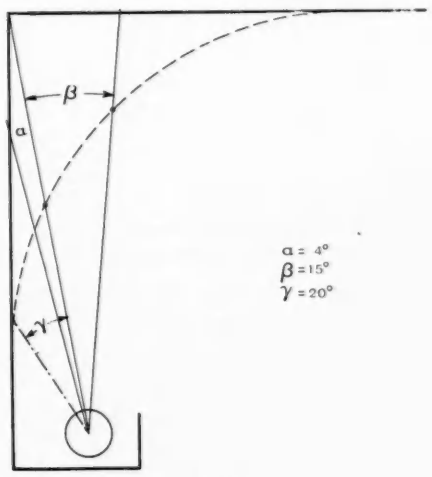


Fig. 11.

reflector might therefore prove dangerous, because an angle of reflection which might be correct from one direction, could be entirely wrong from another. For this reason it is recommended that to ensure maximum efficiency all backgrounds, sides, etc. of built-in fittings should be made matt white. Practical tests carried out with various forms of laylights show that by closing in the backgrounds and sides with matt white reflecting surfaces, the overall light outputs are materially increased.

Having discussed light-reflecting surfaces it is logical to proceed to a consideration of light transmitting media. For most practical purposes the only form of light transmitting medium in general use in architectural lighting is glass, but corresponding to matt and specular reflecting surfaces, there are diffusing and directly transmitting glasses with parallel properties, *i.e.*, the transmission through a completely diffusing glass is independent of the direction from which the original light strikes the glass, while through a directly transmitting glass the light comes out in approximately the same direction as that at which it struck the back of the glass (fig. 12). The most important effect of this difference from a practical point of view is that light sources such as bare electric lamps tend to be directly visible as spots of light when directly transmitting glass is used, whereas an appearance of even brightness may be obtained with a totally diffusing glass. In practice, almost all forms of decorative glassware used in the manufacture of architectural lighting units have a greater or less degree of diffusion, but only very few glasses, such as heavily flashed opal or pot opal, can be considered 100 per cent diffusing. It would appear at first sight that unless a spotty effect is required, the obvious solution would be to employ exclusively opal glass for such purposes; but this would rule out altogether the use of some of those glasses (morocco, raindrop, sandblasted, moulded, etc.), which have the greatest vitality and sparkle, and therefore it may be interesting to examine how spottiness may be controlled or avoided even where an only partially diffusing glass is employed.

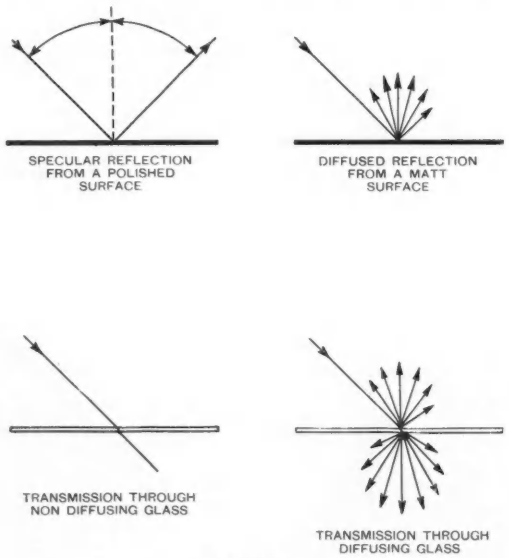

SPECULAR REFLECTION FROM A POLISHED SURFACE
DIFFUSED REFLECTION FROM A MATT SURFACE
TRANSMISSION THROUGH NON DIFFUSING GLASS
TRANSMISSION THROUGH DIFFUSING GLASS

Fig. 12.

The first method is to light the glass panel indirectly off a matt reflecting background (fig. 13). This, however, has the disadvantage that the method of lighting goes a long way towards destroying the natural vitality and sparkle of the glass. This system is therefore only recommended when the space

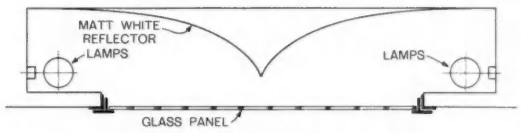


Fig. 13.—Indirect lighting of laylights.

available at the back of the panel is very limited or when it is desired to use a small number of relatively high wattage points in preference to a larger number of smaller points. The second method is to double glaze with a partially diffusing glass such as frosted, set a few inches behind the main glazing (fig. 14). This method has proved very effective in practice, increasing the individual light patch to a degree which renders it inconspicuous and yet preserving to a sufficient extent the sparkle of the glass. The third method is one which does not seek to remove the spots of light but deliberately makes them part

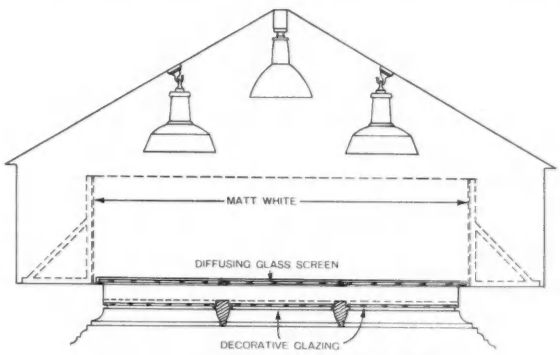


Fig. 14.—Double glazing of laylights.

of the decorative scheme. This method is diagrammatically illustrated in figs. 15, 16 and 17, which represent a square laylight recess which could be adequately and satisfactorily illuminated with four points evenly spaced, as in fig. 15. If the glazing is arranged as in fig. 16, the light patches will clearly bear no logical relation to the glass. If, however, instead of four lamps, nine lamps of lower wattage are employed the result is shown in fig. 17 where each lamp spot will harmonize with the general decorative scheme, and the points of higher intensity

will therefore appear as deliberate high lights instead of accidental patches. It is immaterial whether the glazing scheme is arranged to go with the most economical lamp spacing, or *vice versa*, provided the lamp spacing and decorative scheme are considered as a whole in relation to each other, and not as two quite independent items.

While a diffusing glass prevents the bare lamp appearing as a very bright patch with relatively no apparent illumination between lamps, as is the case with a non-diffusing glass, it is essential that the back of the glass should be evenly illuminated if even illumination is to be apparent on the front. This automatically places a limit on the distance apart at which the lamps can be spaced behind the glass,

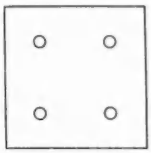


Fig. 15.

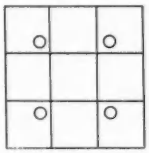


Fig. 16.

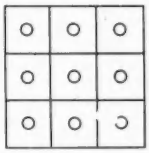


Fig. 17.

and this distance in turn bears a definite relation to the "offset" distance available. The relation between spacing and offset varies with each type of glass according to the measure of its diffusing properties (fig. 18). In this case also, it will be seen that adequate "offset" and space for the housing of the equipment are an advantage in that the user can adopt the simplest and most economical method of lighting for the area, instead of being forced to adopt a lamp spacing dictated by the limitation of space.

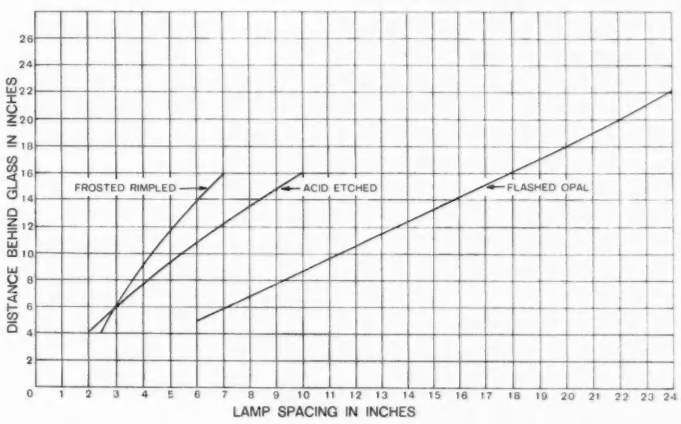


Fig. 18.—Relation between spacing and offset of lamps for apparent even illumination of glass panels.

Many other striking effects can be obtained by arranging glassware and light in the correct relation to each other; the repetitions of filament image in glass rods or prisms, the sparkle of etched patterns illuminated through the edge of the glass are typical examples, but to obtain any of these effects an understanding of what causes them is essential.

The question of maintenance is important. Lighting fittings require periodical re-lamping, they may require ventilation, but most important of all, they require regular cleaning. Reflecting surfaces and transmitting media alike will rapidly lose both their efficiency and their vitality unless they are kept properly cleaned, and for this reason simplicity of construction from the maintenance aspect is of supreme importance. Where fittings are mounted in reasonably accessible positions, this problem is mainly one of fittings construction, but where they are introduced in positions at heights not easily accessible from the floor, the problem may well become one of building construction, and for this reason consideration of the lighting scheme before the building plans have proceeded too far is essential.

The question of the ventilation not only of the fittings but also of the room itself must be considered, and in many architectural lighting schemes the extracts in connection with the air conditioning of the room are incorporated in the lighting features, and so many square inches of space will be demanded by the ventilating engineer. In such cases it is clear that both the design and method of construction of the lighting fittings may be materially affected.

In conclusion, it is desirable to refer briefly to the effect of light on various decorative media, and *vice versa*.

Obviously the lighting fittings must harmonize in shape, proportion and finish with the general decorative scheme; but this is not sufficient. The actual texture and finish of the paints and fabrics used to decorate the room will have a material bearing on its appearance under any artificial lighting system, and a good general lighting effect may easily be marred if the surface treatment of walls and ceiling is unsuitable. The most familiar manifestation of this is where a glossy ceiling finish reflects every light source as a streak of light. Such an effect deliberately contrived may be very good, but more frequently it is unintended and unsightly (*see figs.* 1, 9 *and* 20). Another example is the effect of coloured light on colours, as for instance, if a warm amber tone of light is used in a room where the colour scheme is predominantly blue or green. In such a case the colours of the decorations may easily appear muddy whereas correct choice of light would enhance them. The problem, however, goes far deeper than this, and correctly chosen lighting may be designed to give vitality to curtains, wallpapers, upholstery,

etc., where an incorrectly designed scheme would leave them lifeless and dull. As stated earlier in this article, this subject does not appear to have been investigated as fully as is desirable, but already advanced decorative lighting designers are not only choosing their light to bring out the beauty of texture and form of the media employed in the general decorative scheme, but (*vice versa*) are choosing decorative media which are the most effective distributors of reflected light.

Fig. 19.—This artificial laylight in the library of the Royal Society is illuminated in the manner shown in fig. 14.

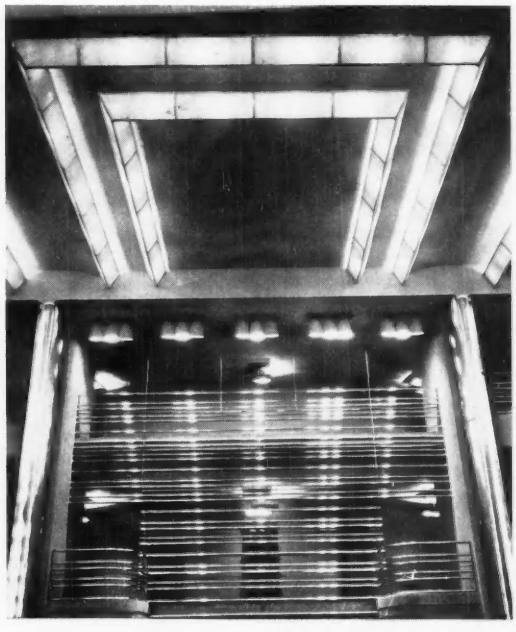
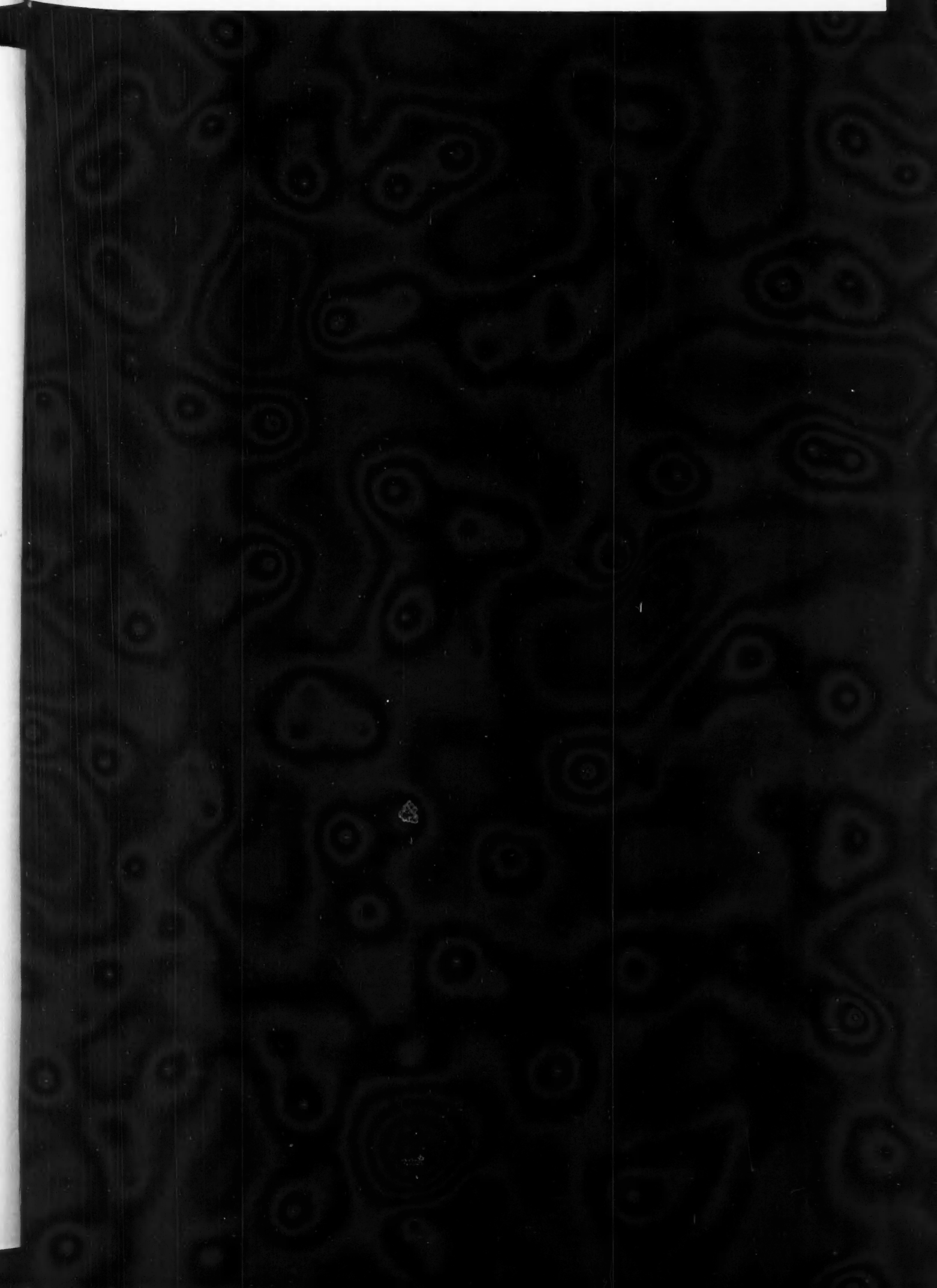


Fig. 20.—Uneven illumination on glassware and specular reflections combine to spoil this effect.

Fig. 21.—Illustrating how light can be used to alter the appearance of general decorative treatment. The light and shade contrast on the frieze is contrived by the use of directional lighting on to identical fabrics placed at a different angle in relation to the incidental light.



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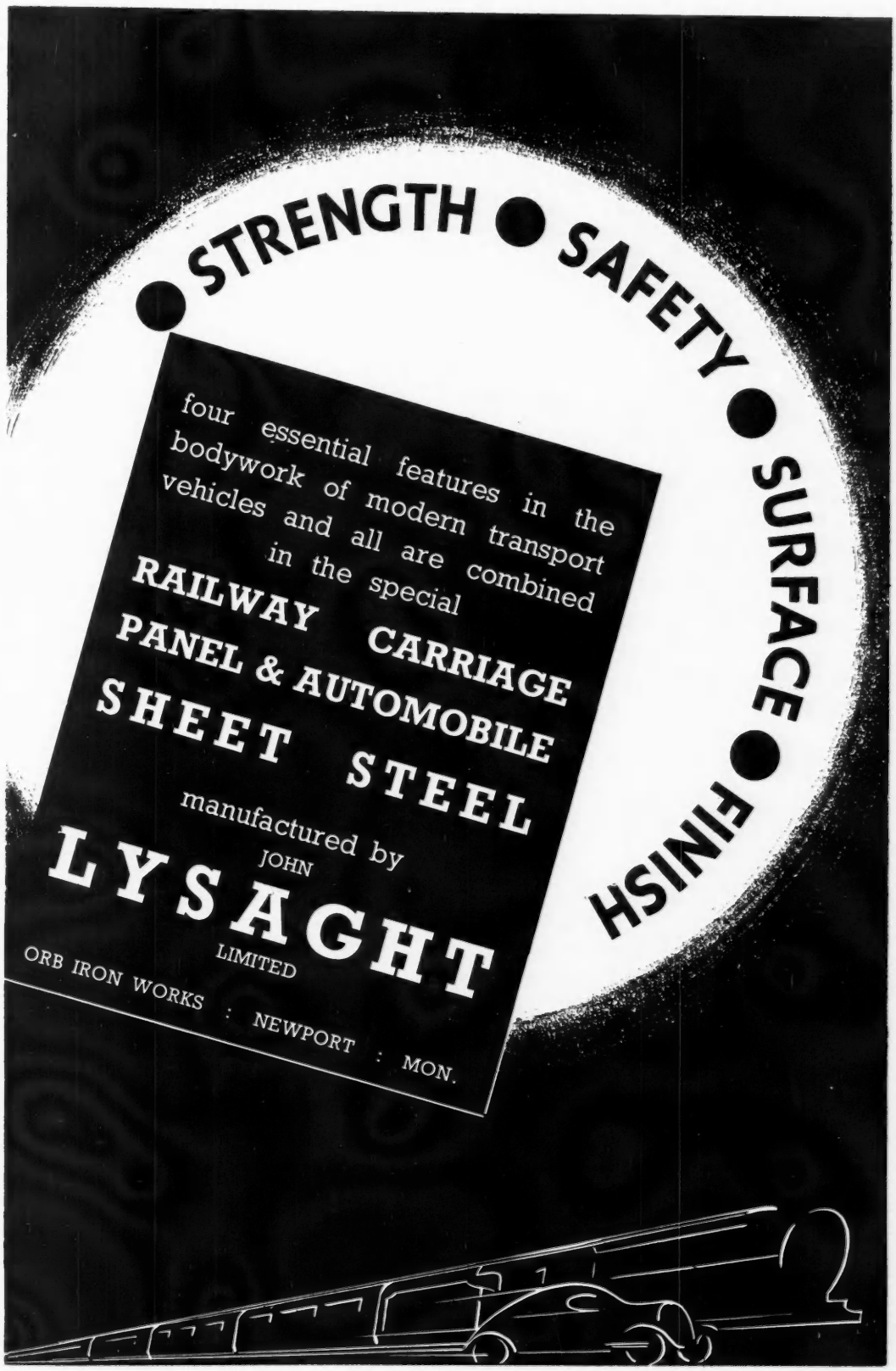
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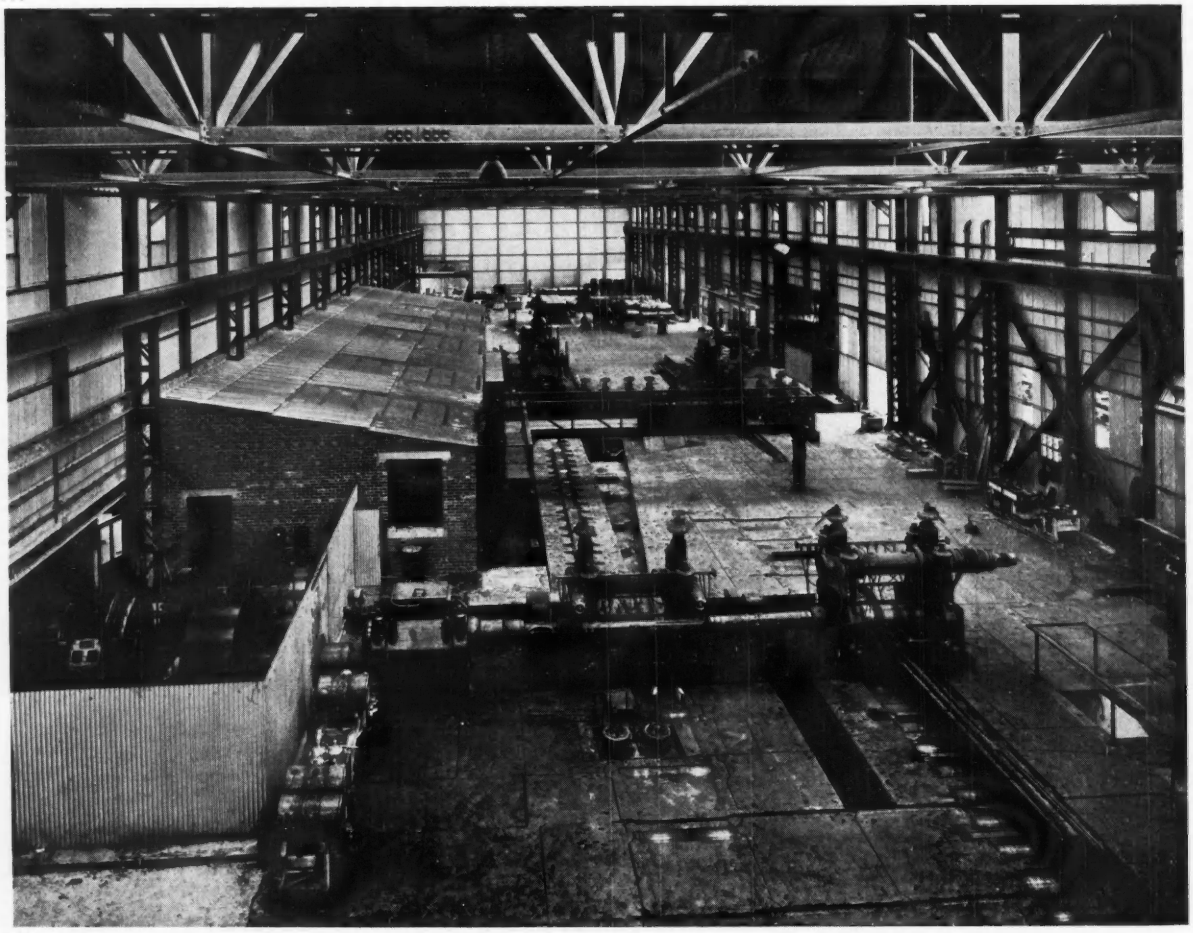

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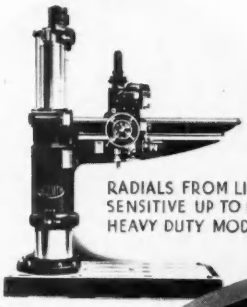

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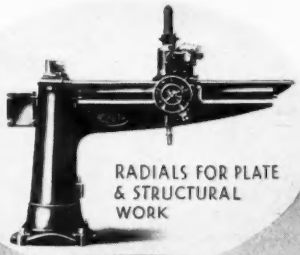

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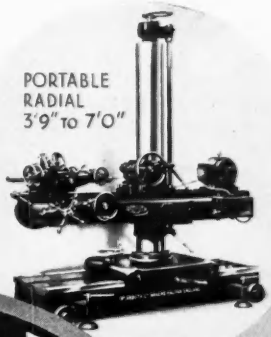

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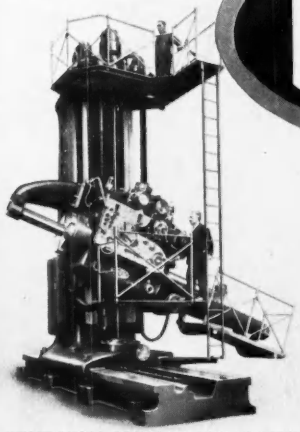

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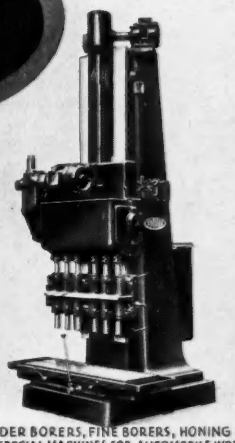

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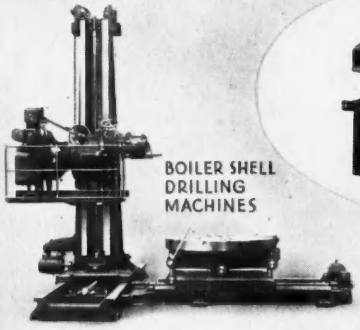

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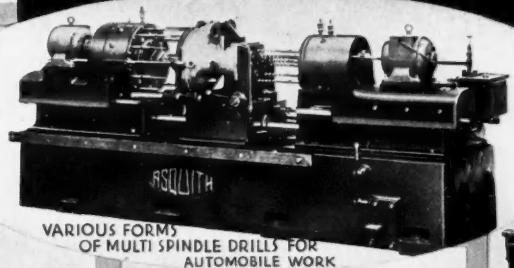
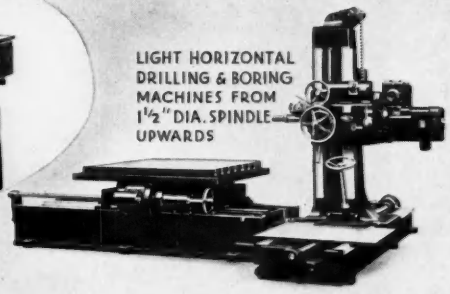
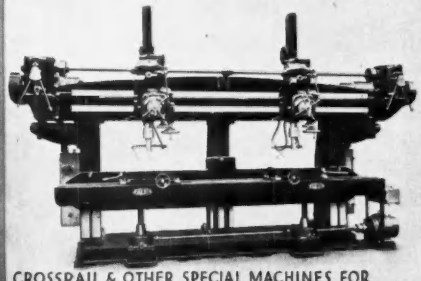


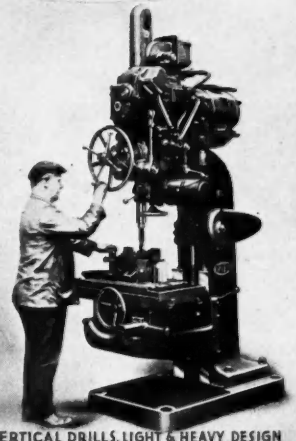
VARIOUS FORMS OF MULTI SPINDLE DRILLS FOR AUTOMOBILE WORK



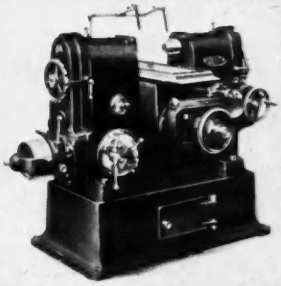
LIGHT HORIZONTAL DRILLING & BORING MACHINES FROM 1½"DIA. SPINDLE UPWARDS



CROSSRAIL & OTHER SPECIAL MACHINES FOR LOCOMOTIVE, BOILER, CARRIAGE & WAGON WORK



VERTICAL DRILLS, LIGHT & HEAVY DESIGN VARIOUS FORMS OF WORKTABLES



KEYSEATING & COTTERWAY MACHINES

MACHINERY

WILLIAM ASQUITH LTD., HALIFAX.

G.E.C. ELECTRODE BOILERS

(PENZOLD SYSTEM)

Installation at MERSEY TUNNEL OFFICES

500 kW G.E.C. low tension electrode water heater, used with thermal storage equipment and patent embedded warm water panel heating system at the Mersey Tunnel offices and ventilating block, Georges Dock, Liverpool.

This installation typifies a rapidly extending application of electric water heating.

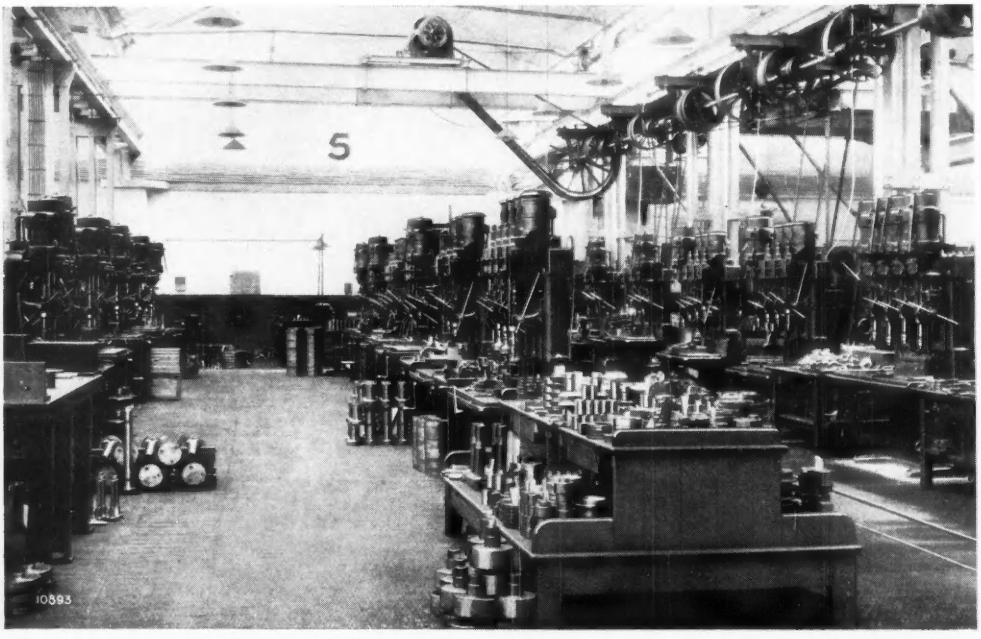
Its use for the central heating of large buildings and for factories, laundries, dairies and such places where steam is required for process purposes offers pronounced advantages.

View in the main galley, showing the G.E.C. 14-oven island electric range.

Launched by the Duchess of York in April last the S.S. "STRATHMORE" is the largest passenger vessel yet built for the P. & O. Company.

G.E.C. electric cooking equipment is employed throughout, some of the more important items being the 14-oven island range illustrated above, a fish fryer, grills, a double deck bread baking oven, and special apparatus for cooking for the native crew.

HERBERT



A view of our own Drilling Department where we have replaced 76 old pattern spindles by 51 Herbert new pattern All-electric Spindles and in so doing have disposed of nearly 4 tons of overhead driving gear. The capacity of the department has been increased by 25%.

50% REDUCTION IN DRILLING COSTS.

THIS saving is not unusual when Herbert Patent All-Electric Ball-Bearing Drilling Machines with their instantaneous finger-controlled speed changing, starting, stopping and reversing are installed in place of ordinary drilling machines. It is generally found that 25% fewer spindles are required to do the same amount of work.

Machines are made for general work, manufacturing, tapping, woodworking, also high-speed machines for bench or column, permitting speeds up to 12,000 r.p.m.

Spindle guards, a necessity for safety are included in the price and a grease-gun is supplied with each machine.

MADE WITH 1, 2, 3, 4 and 6 SPINDLES. Plain and geared. Drills up to $1\frac{1}{4}''$ dia. in cast iron, $1\frac{1}{8}''$ in steel. Taps up to $1\frac{1}{4}''$ in cast iron, $1''$ in steel.

ALFRED HERBERT LTD. COVENTRY

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G.E.C. Journal

IN THIS ISSUE.

HIGH FREQUENCY ELECTRIC MELTING FURNACE EQUIPMENT

MAGNETRON VALVES FOR ULTRA-SHORT WAVELENGTHS

THE TESTING OF LARGE A.C. CIRCUIT BREAKERS PARTS II. AND III.

A NEW LEAD EXTRUDING MACHINE

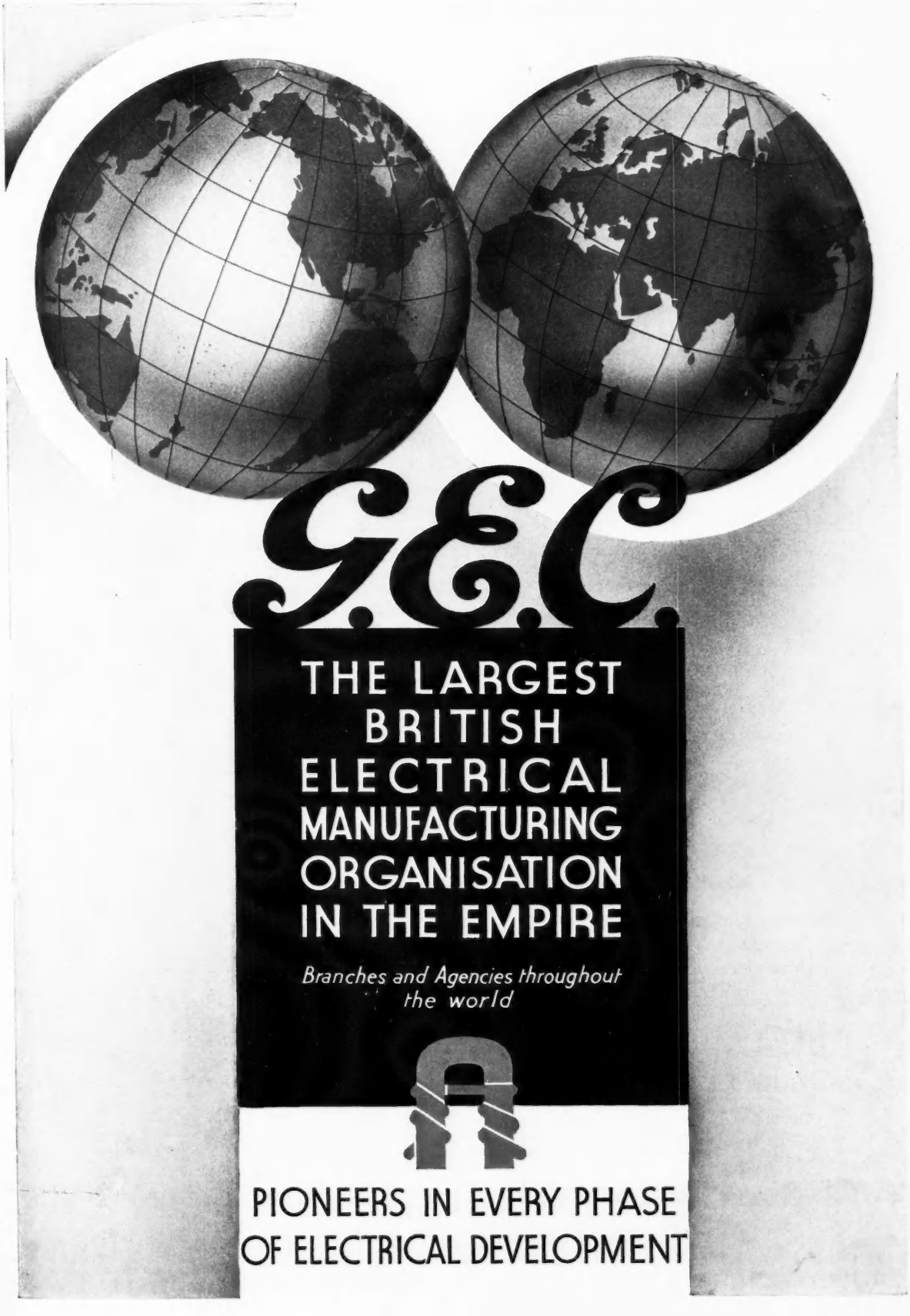
TURBO-BLOWERS AND TURBO-COMPRESSORS PART III.

ELECTRIC ARC WELDING

VOLTAGE REGULATION OF A.C. TRANSMISSION AND DISTRIBUTION SYSTEMS

Vol. VII., No. 2. *May, 1936.*

THE GENERAL ELECTRIC CO. LTD
ENGLAND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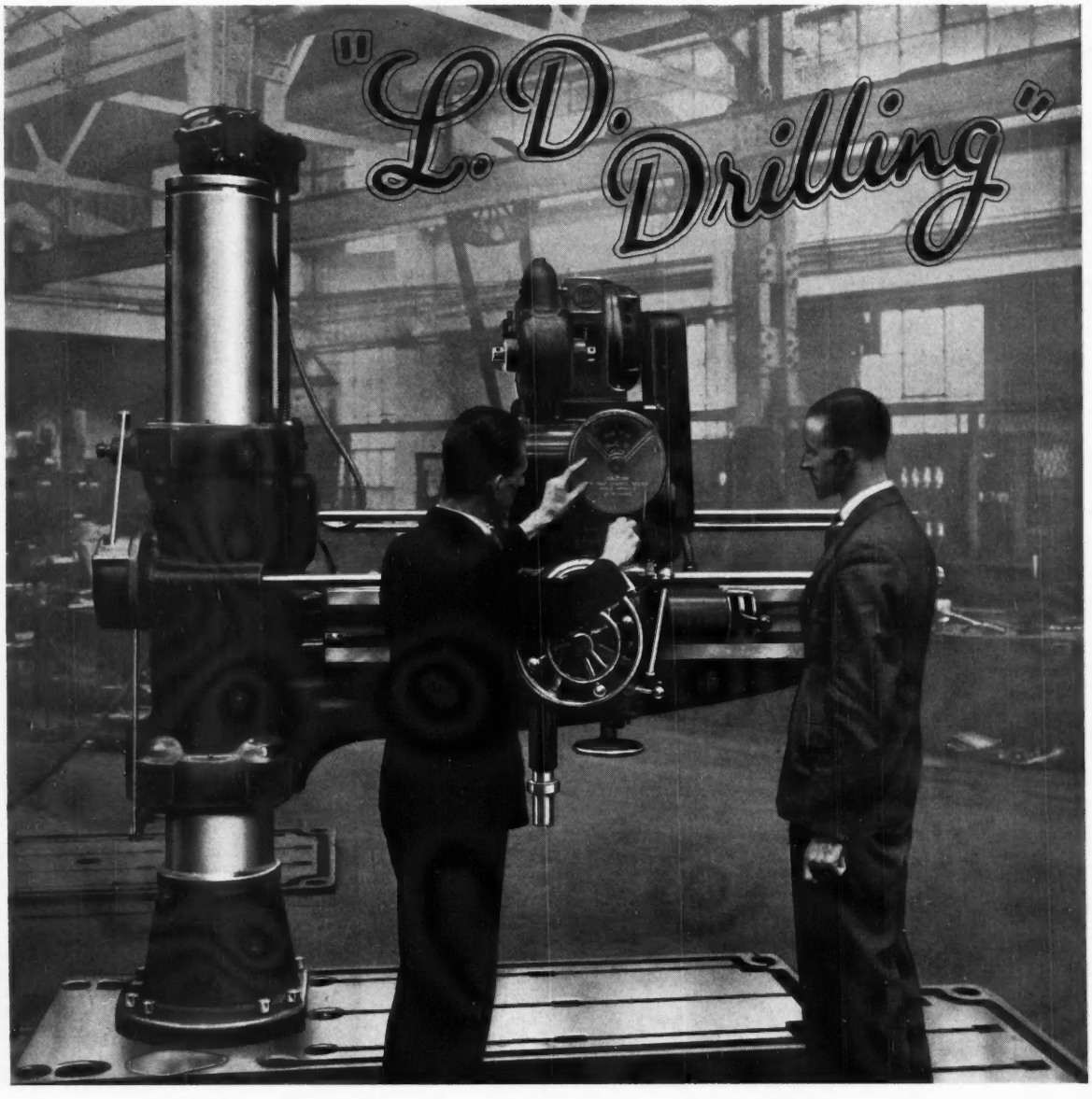
PIONEERS IN EVERY PHASE OF ELECTRICAL DEVELOPMENT



"Cast iron, steel, aluminium, bronze. Just set the disc against the material, bring the hole diameter into view by operating the lever, and the spindle automatically runs at the correct rate.

"Nine changes, I see, with three separate feeds. And the reverse is electrical ?

"Yes, there are no clutches whatever in the drive. That source of irritation is gone for ever in the Asquith L. D.—as also in our well-known "O.D." and "S.C." models.

A conversation bearing on two important contributory points to the all-round excellence of this design—the latest Asquith L.D.

Other features in brief include the noiseless V-belt drive, single lever for spindle stop, start and reverse, and arm elevate, combined locking lever for slide and arm, extremely facile adjustments, and focalized control on the slide.

Full details and prices on application.

WILLIAM ASQUITH, LIMITED, WELL ROAD WORKS HALIFAX

Sole Representatives for the Midlands and Southern Counties of England :

DRUMMOND (SALES) LTD., 8, WATERLOO ST., BIRMINGHAM, 2

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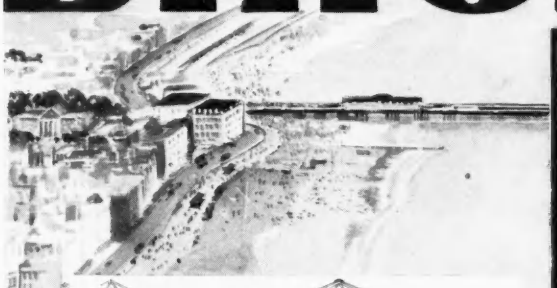

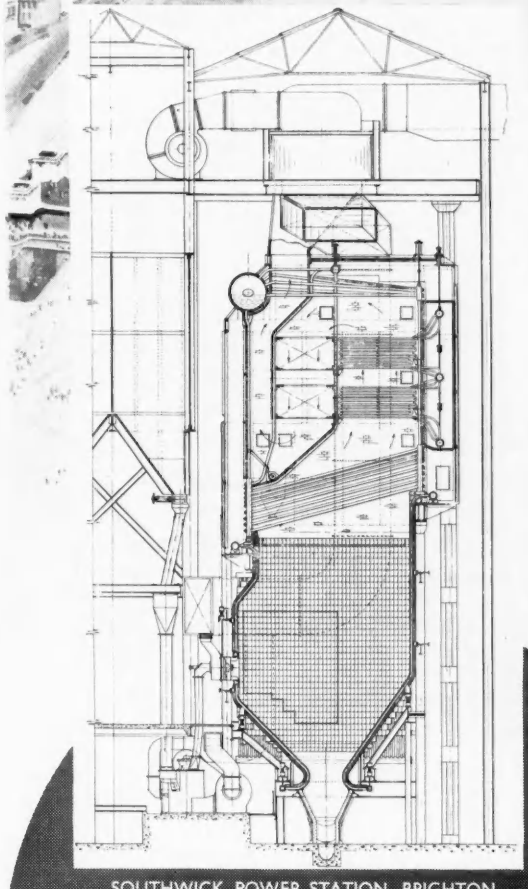

SOUTHWICK POWER STATION, BRIGHTON.

Two B. & W. Boilers now under construction are each of 8,040 sq. ft. h.s., for a normal load of 175,000 lbs/hr. at 675 lbs/sq. in. and 875°F.

These boilers, with Bailey hopper bottom furnaces and Babcock direct firing equipment for pulverised fuel represent typical modern design.

The side sectional elevation of the units reproduced above will give an impression of competent design ensuring a high output per unit of space occupied.

SOME BABCOCK & WILCOX PULVERISED FUEL INSTALLATIONS

NAME	No. of Boilers	Pressure– Lbs./sq.in.	Capacity– Lbs./hr./blr.
Amanogawa	4	483	120,000
Brighton	2	675	175,000
Broken Hill	1	200	60,000
Beresnikovsky	4	853	330,000
Betteshanger	2	200	55,000
Belqas	3	440	46,800
Barton	1	375	130,000
Catania	1	370	110,000
Callenders Cables	4	275	20,000
Chosen Denryoku	4	455	132,000
Dunston	2	625	156,000
Dutch States Mines	2	500	220,000
Figols	2	355	77,000
Ford Motor	2	200	40,250
Ford Motor	3	1,250	205,000
Gravenhage	2	298	77,000
Gravenhage	2	384	220,000
Hokkaido Dento	1	455	143,000
Hayle	1	250	62,500
Horden Collieries	3	200	60,000
I.C.I.	1	200	50,000
I.C.I.	1	575	77,000
I.C.I.	2	625	150,000
I.G.R. Japan	4	384	132,000
Ironbridge	3	400	270,000
Kumamoto Denki	6	580	233,000
Kansai	4	600	319,000
Korean Corn Products	2	400	54,000
Kyushiu	2	550	280,000
Kashira	5	426	423,200
Londonderry Collieries	2	200	36,000
Langreo	4	200	36,000
Liverpool	3	300	125,000
Mount Isa Mines	3	270	62,500
Mitsui Dyestuff	2	745	186,000
Mitsui Mining	2	385	80,500
Nippon Seitetsu	2	426	153,000
Nippon Seitetsu	2	429	126,500
Nippon Rayon	3	425	132,000
Norsk Hydro	3	540	60,000
North Met.	2	200	90,000
Powell Duffryn	3	150	50,000
Powell Duffryn	1	160	30,000
Poznanski	1	340	75,000
Roan Antelope	4	275	67,500
Rosario	2	356	66,000
Rotterdam	1	199	57,200
Rotterdam	3	427	220,460
Seisen Godo	2	225	50,000
Saka Power	3	489	168,000
St. Pancras	1	250	60,000
Sanyo Chuo	4	650	165,000
St. Denis	8	313	121,000
St. Denis	6	1,000	240,000
Tsurumi	4	640	375,000
Tsurumi	3	375	180,000
Ultimo	6	360	110,000
York Street Flax	1	280	50,000
Yamaguchi	3	520	264,000

BABCOCK & WILCOX LTD BABCOCK HOUSE FARRINGDON STREET LONDON E.C.4

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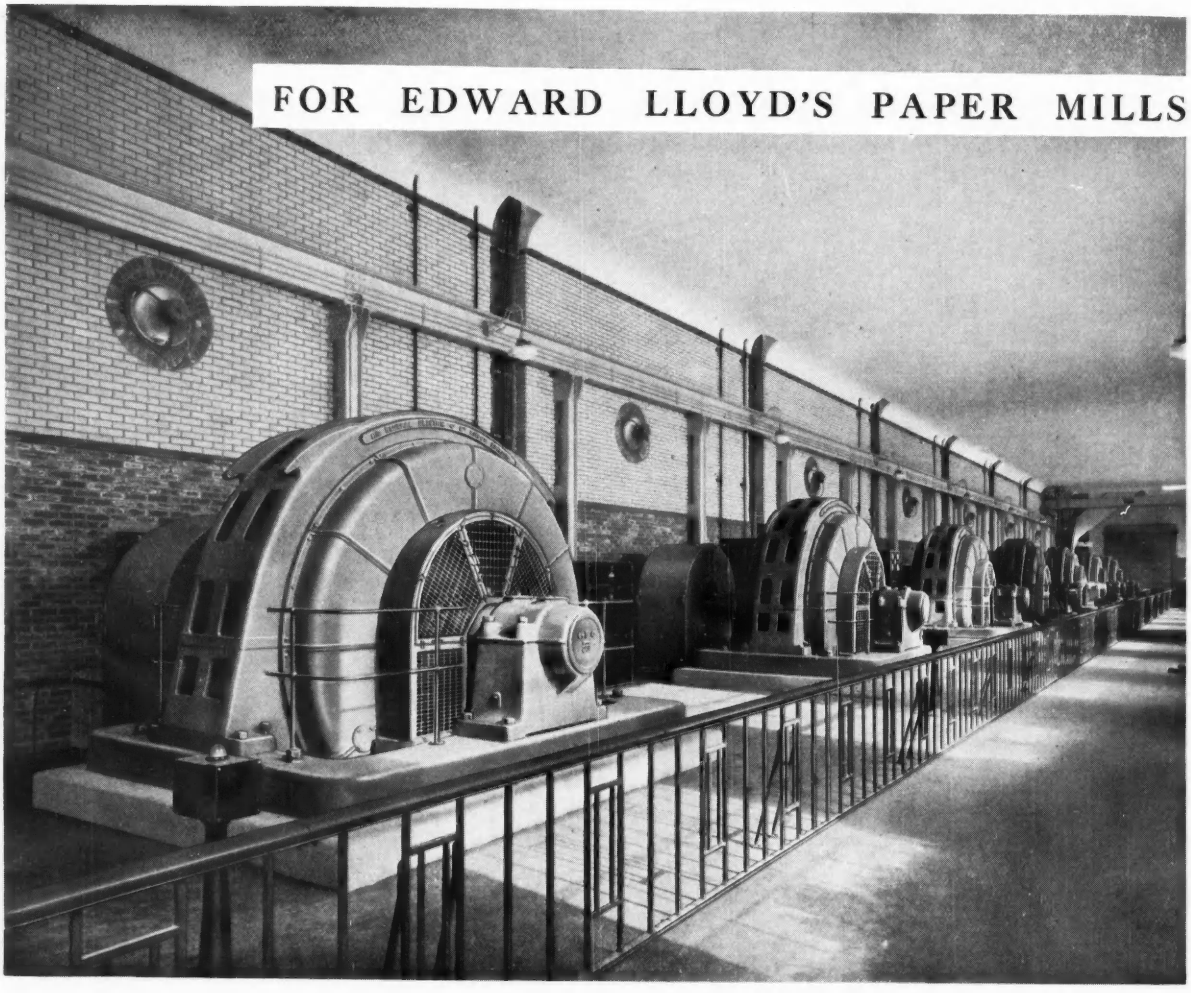
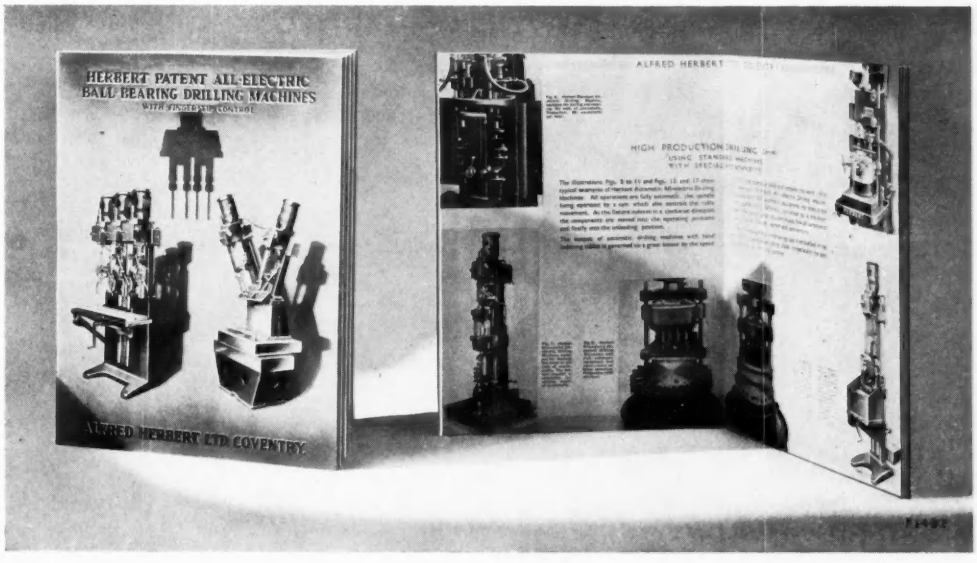
POWER PLANT

FOR EDWARD LLOYD'S PAPER MILLS



Seven 2,500 h.p. WITTON motors driving new paper mill plant for process work. Each motor is provided with a phase advancer. Other equipment supplied by the G.E.C. for the extensions to this important paper mill includes a 14-panel 6,600 volt truck cubicle switchboard, one of the largest of this type ever built.

HERBERT



HERBERT ALL-ELECTRIC BALL-BEARING DRILLING MACHINES

FIRMS who have replaced ordinary drilling machines by Herbert Patent All-Electric Drilling Machines with finger-tip control and instantaneous starting, stopping and reversing have effected the following savings:

25% fewer spindles are required to do the same amount of work and up to 50% saving in production times is effected.

Spindles can be started, stopped or reversed instantly, a necessity for safety.

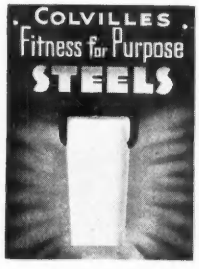
Made with 1, 2, 3, 4 or 6 spindles, plain or geared.
Drills up to $1\frac{1}{4}''$ in cast iron, $1\frac{1}{8}''$ in steel.
Taps up to $1\frac{1}{4}''$ in cast iron, $1''$ in steel.

Our booklet on high-production drilling will be sent on request.

PROMPT DELIVERY.

ALFRED HERBERT LTD. COVENTRY

COLVILLES "BIG FIVE"



"DALZO" Rust Resisting—Structures, Towers, Tanks, Sheets & Tunnel Plates. *(Approved by the B.O.T. for various parts of Life Boats).*

"DUCOL" Weight Saving—Boiler Shells, Shipfittings, Etc. *(Approved by Lloyds, B.C. and B.V. for Marine Construction).*

"COLMO" High Limiting Creep Stress—Superheater Tubes, Etc.

"PYRO 68" Heat Resisting—Oil Cracking Plant, Etc. *(Non-scaling up to 800° centigrade).*

"MARTINEL" High Elastic Limit—Marine Construction. *(Manufactured to the order of the Martinel Steel Co. Ltd., under registered Trade Mark No. 508904).*

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G.E.C.

ELECTRIC FURNACES

FOR THE GRUNEWALD PROCESS

Bright annealing of a perfectly uniform and lasting character is being obtained in many works where G.E.C. furnaces for the Grunewald process are installed.

This is a dry process, and no artificial gas atmosphere is needed.

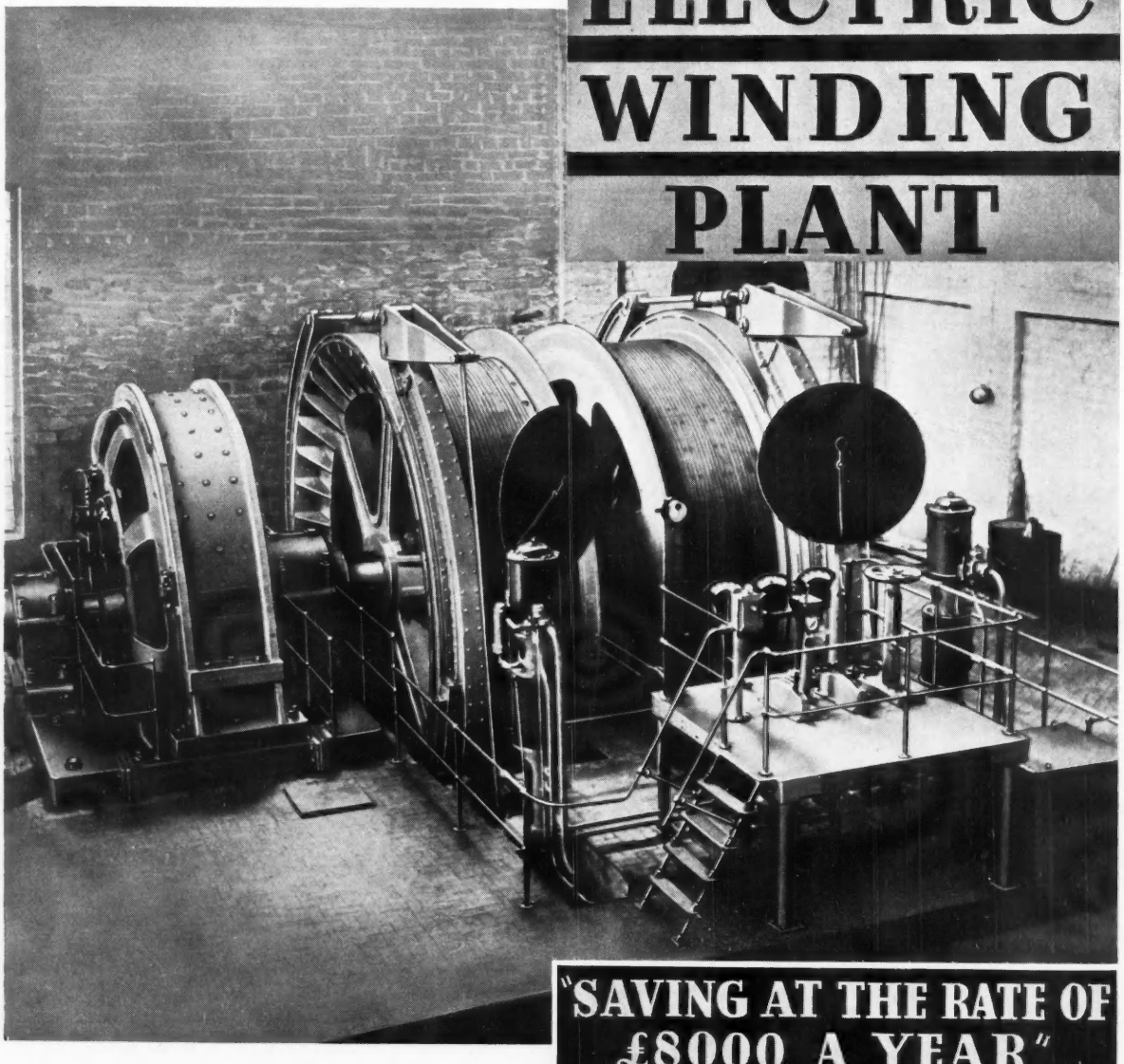
A CHARGE OF COLD ROLLED STEEL STRIP IN COURSE OF WITHDRAWAL FROM A GRUNEWALD BRIGHT ANNEALING POT.

An installation comprising two G.E.C. vertical cylindrical furnaces and 16 Grunewald (Patent) annealing pots, at the works of J. J. Habershon & Sons Ltd., Holmes, Rotherham.

G.E.C.
REG? TRADE MARK

FRASER and CHALMERS

ELECTRIC WINDING PLANT



"SAVING AT THE RATE OF £8,000 A YEAR"

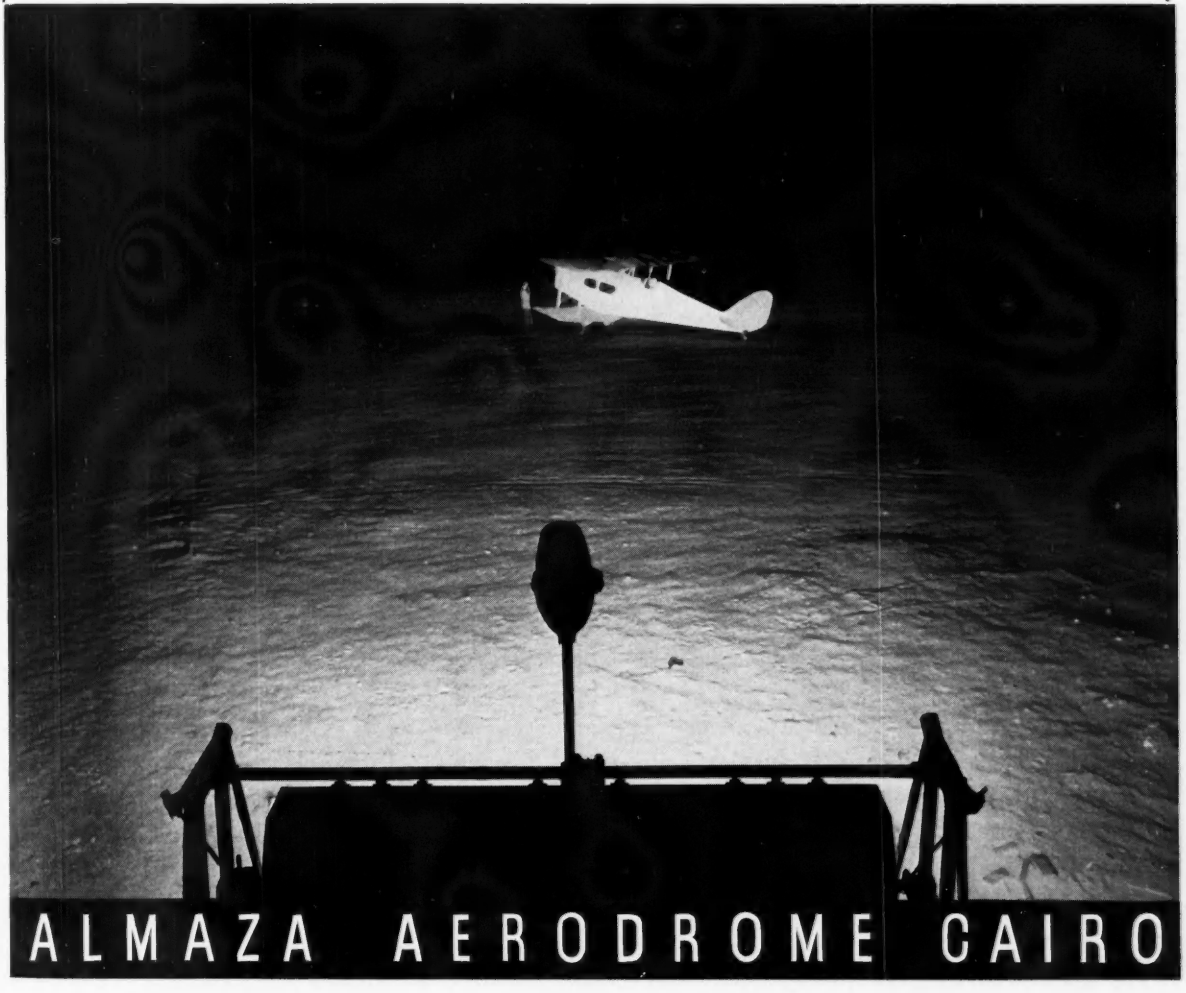
This 1,150-h.p. electric winder, installed at the Champion Reef Gold Mines, South India, is designed to hoist 5,300 lbs. per wind from a vertical depth of 3,633 feet.

Evidence of the success of this plant is given in the following statement by the mine managers: ". . . A substantial saving is being realised in hoisting costs . . . The saving is at the rate of £8,000 a year."

G.E.C.

AERODROME LIGHTING EQUIPMENT

The range of special equipment developed by the G.E.C. for aerodrome lighting is now being used extensively in India, Africa, Egypt and other overseas aerodromes, as well as at Croydon and many important aviation centres in Great Britain.



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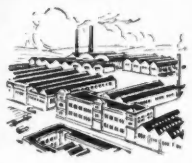

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IN THIS ISSUE.

THE LIGHTING AND TELEPHONE SYSTEM OF THE R.M.S. "QUEEN MARY"

THE DEVELOPMENT OF LARGE RADIO TRANSMITTING VALVES

METALCLAD SWITCHGEAR AT CARDIFF

AUTOMATIC CONTROL OF ROAD TRAFFIC PART I.

THE TESTING OF LARGE A.C. CIRCUIT BREAKERS PARTS IV. & V.

POWER PLANT REORGANIZATION AT HAMSTEAD COLLIERY

Vol. VII., No. 3. *August, 1936.*

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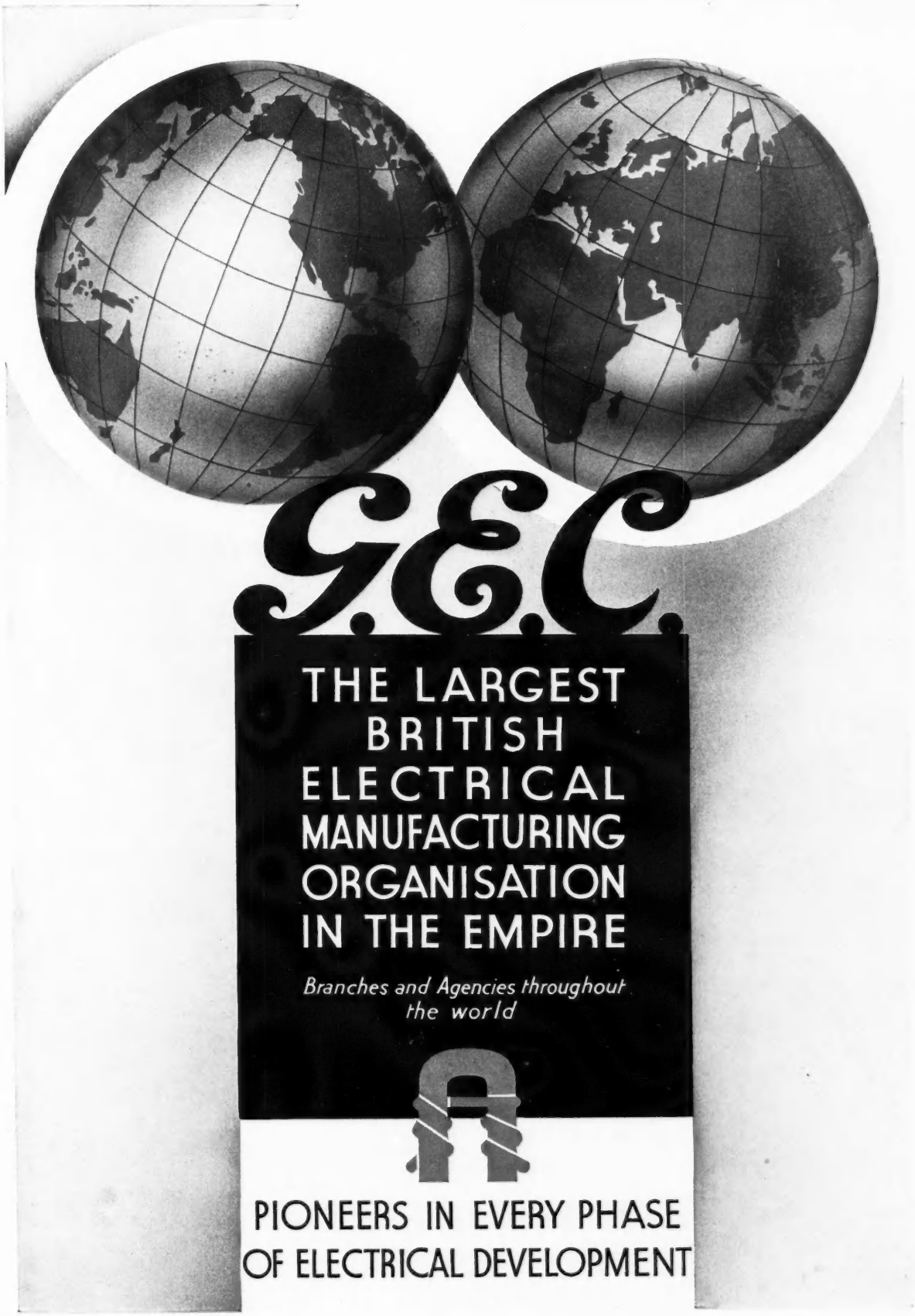
ENGLAND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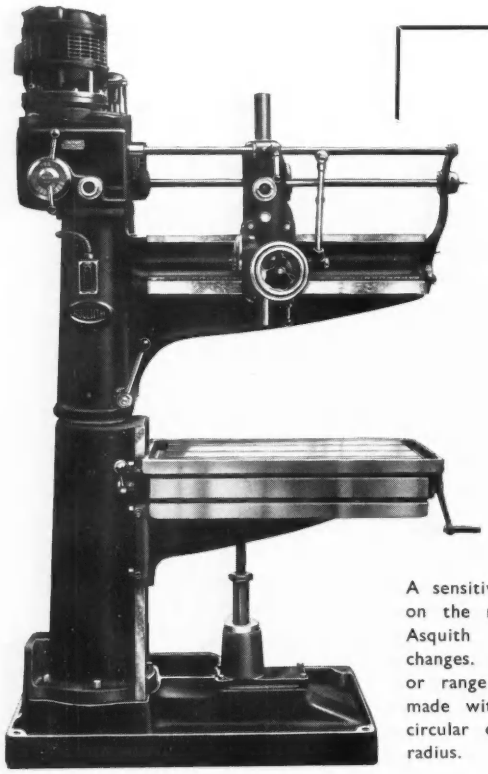


A sensitive and radial drill built on the most modern lines—the Asquith "S. D." Nine speed changes. Sensitive lever feed only or range of power feeds. Also made with swing-away table on circular column, 2ft. 7in. to 4ft. radius.

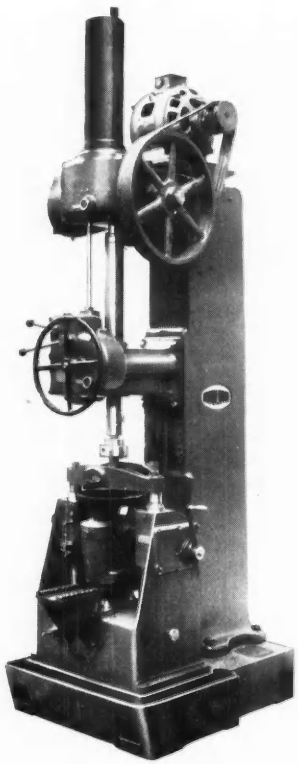


Illustration above shows a new rigid type of vertical drill, the "U.F.D." with adjustable spindle supporting bracket. Made either as a single spindle machine or as "driver" for multiple heads, etc. Drop worm for feed engage. Speeds and feeds variable by slip gears.

MODERN LINES

Details of either of the foregoing gladly furnished upon request. Other recently developed lines include an extra heavy radial drill and a range of light vertical drilling and tapping machines. Remember—all our products are backed by over 50 years' specialised experience.

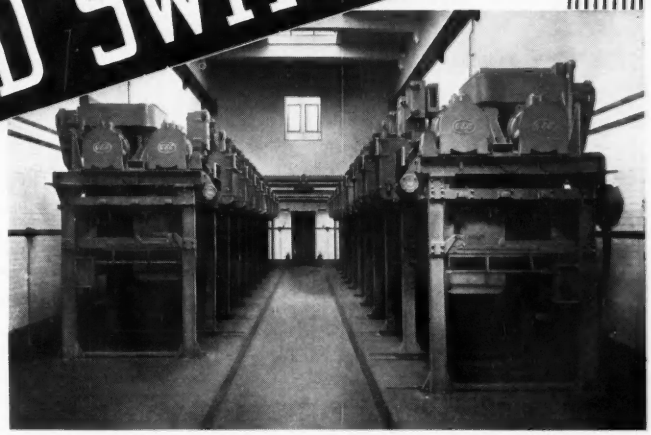
WILLIAM ASQUITH LTD., WELL ROAD WORKS, HALIFAX.

Sole Representatives for the Midlands and Southern Counties of England:

DRUMMOND (SALES) LTD., 8, WATERLOO ST., BIRMINGHAM, 2.

G.E.C.

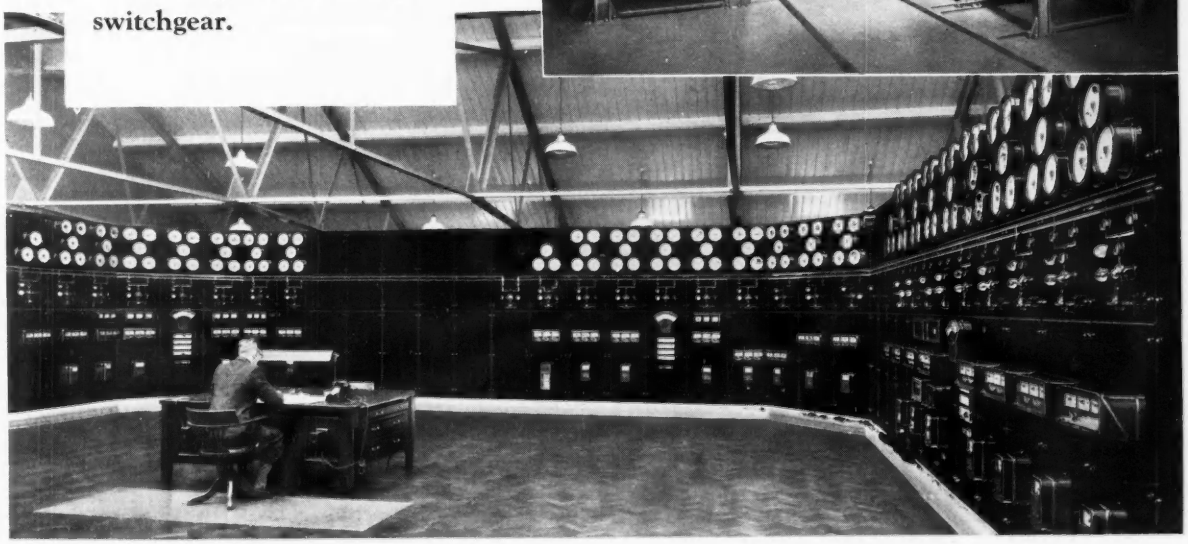
METAL CLAD SWITCHGEAR



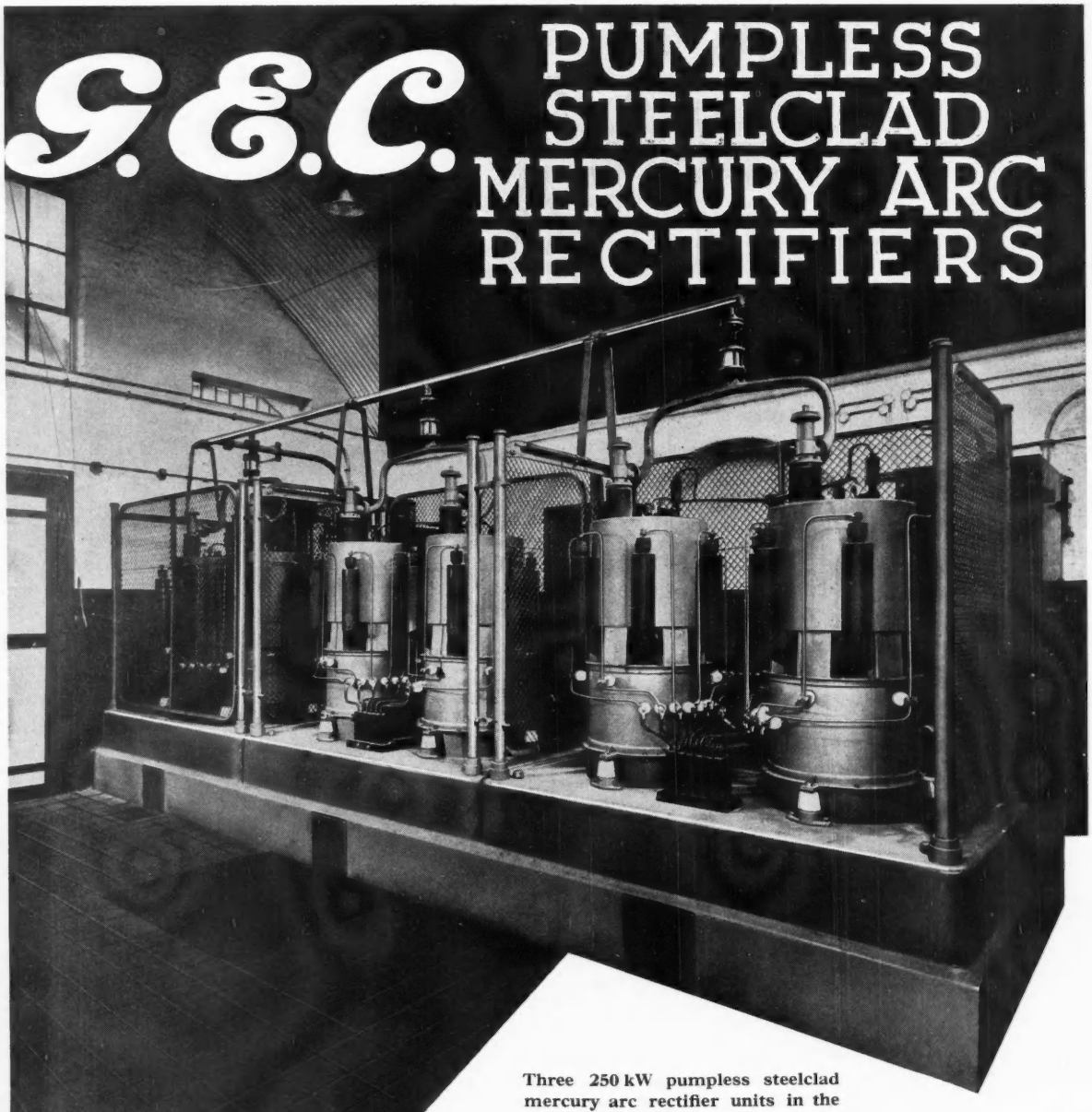
The two metalclad switchgear bays.

Wolverhampton Corporation's new switchgear house is equipped with G.E.C. metalclad switchgear.

The equipment supplied comprises the control board shown in the lower illustration and forty 500,000 kVA 6,600 volt metalclad switchgear units. These are installed in two main rooms, each containing two banks of switchgear.



G.E.C. PUMPLESS STEELCLAD MERCURY ARC RECTIFIERS



Three 250 kW pumpless steelclad mercury arc rectifier units in the Putney Bridge Sub-station of the London Passenger Transport Board

THE FIRST INSTALLATION OF PUMPLESS STEELCLAD MERCURY ARC RECTIFIERS IN THE WORLD. This new type of rectifying unit represents one of the most outstanding achievements of recent engineering research. The entire experimental and development work involved was carried out in the G.E.C. development department at Witton Engineering Works.

BAILEY FURNACES

ALL OVER THE WORLD

BAILEY WALL INSTALLATIONS TO APRIL 30TH 1936

AUSTRALIA	6
BELGIUM	5
CANADA	21
DENMARK	10
FINLAND	11
FRANCE	18
GREAT BRITAIN	197
HOLLAND	22
INDIA	6
ITALY	2
JAPAN	66
MANCHURIA & KOREA	10
NEW ZEALAND	2
POLAND	1
SOUTH AFRICA	49
SOUTH AMERICA	10
SPAIN	2
SWEDEN	1
U.S.A.	582
U.S.S.R.	17
TOTAL	1038

The illustrations show the Bailey Block Shipping and Packing Departments in our Renfrew Works, from where consignments are sent all over the world. The security of packing is in accordance with the care exercised in design, manufacture and erection, to ensure years of trouble-free furnace life under the most severe operating conditions imposed upon the modern water tube boiler.

To April 30th, 1936, there were installed or on order 1038 Bailey Furnaces, of which 40% are in Industrial Plants and the balance in Central Power Stations. It is evident that leading Engineers throughout the world appreciate Bailey water cooled furnace construction as being the cheapest means of ensuring continuity of operation.

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FRASER & CHALMERS

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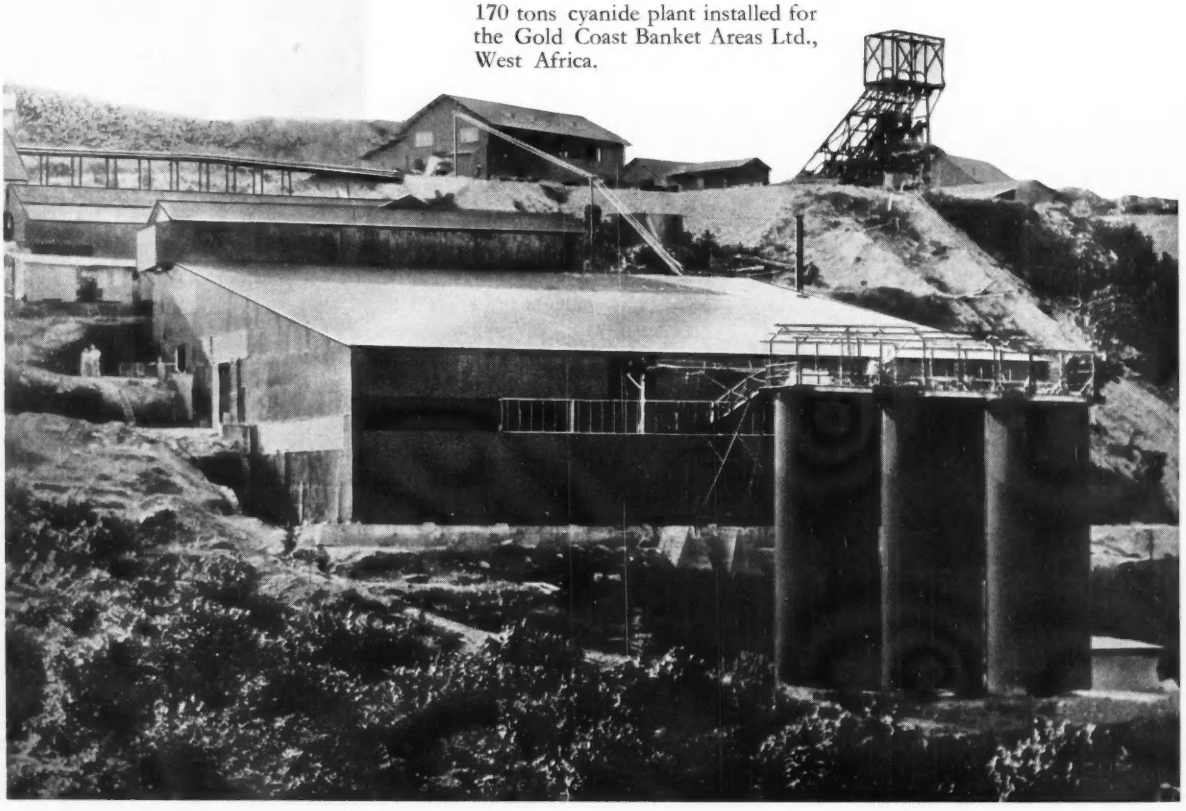
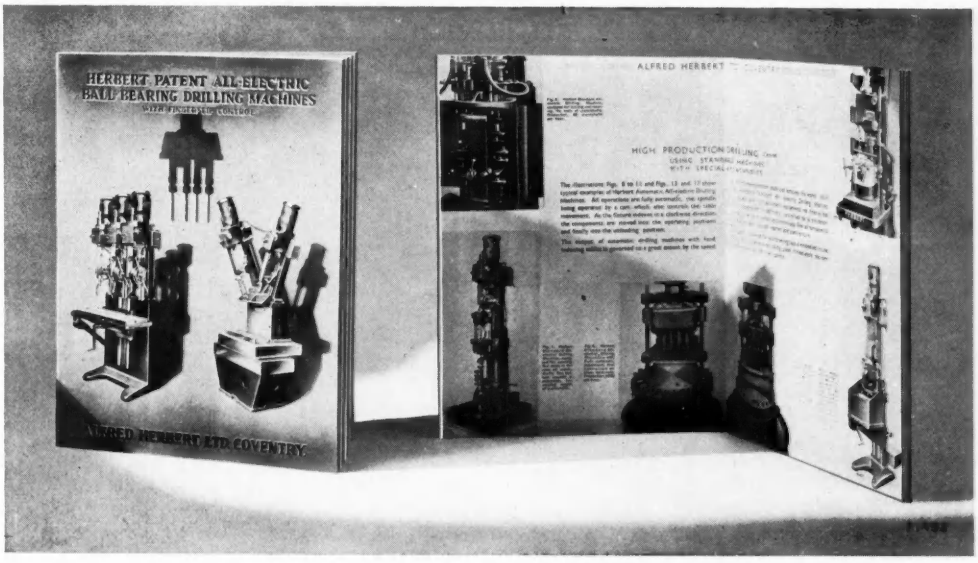
Complete mining and metallurgical plants are manufactured here for erection in any part of the world.

170 tons cyanide plant installed for the Gold Coast Banket Areas Ltd., West Africa.



HERBERT



HERBERT ALL-ELECTRIC BALL-BEARING DRILLING MACHINES

FIRMS who have replaced ordinary drilling machines by Herbert Patent All-Electric Drilling Machines with finger-tip control and instantaneous starting, stopping and reversing have effected the following savings:

25% fewer spindles are required to do the same amount of work and up to 50% saving in production times is effected.

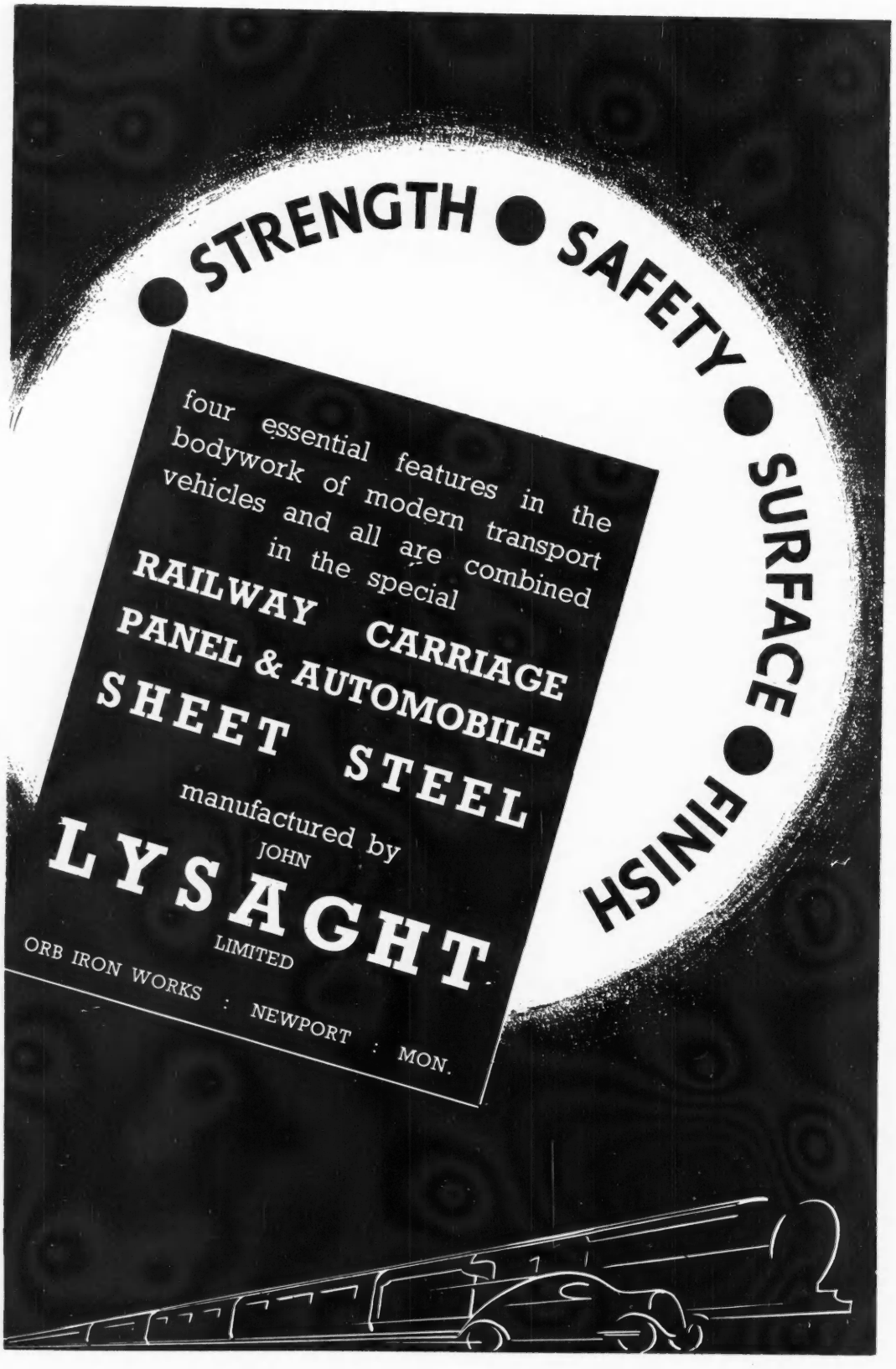
Spindles can be started, stopped or reversed instantly, a necessity for safety.

Made with 1, 2, 3, 4 or 6 spindles, plain or geared.
Drills up to $1\frac{1}{4}''$ in cast iron, $1\frac{1}{8}''$ in steel.
Taps up to $1\frac{1}{4}''$ in cast iron, $1''$ in steel.

Our booklet on high-production drilling will be sent on request.

PROMPT DELIVERY.

ALFRED HERBERT LTD. COVENTRY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manufactured by
JOHN
LYSAGHT
LIMITED
ORB IRON WORKS : NEWPORT : MON.

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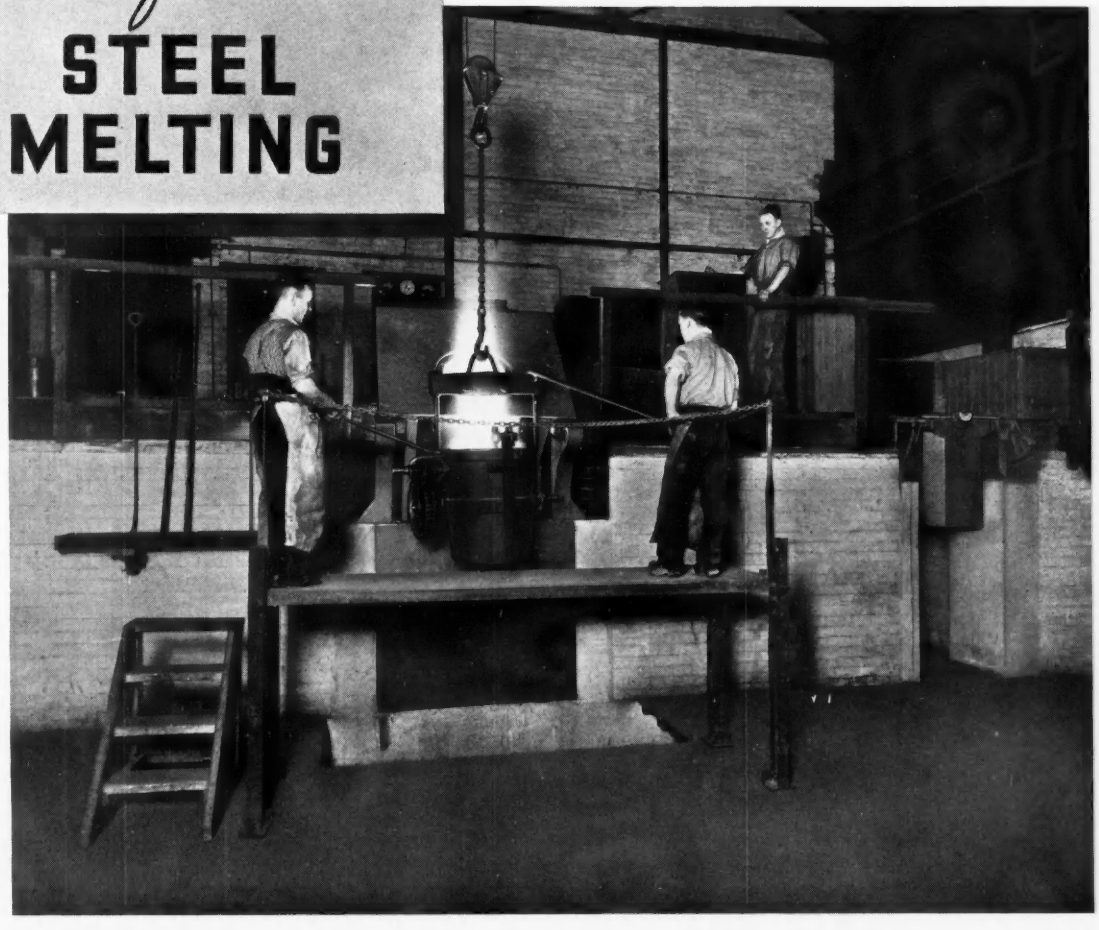
MADE IN ENGLAND

for

STEEL MELTING



Installation at the works of

JONAS & COLVER (NOVO) LTD.

SHEFFIELD.

Two WITTON high frequency electric melting furnaces, one of half-ton capacity and the other 100 lbs. (Stobie Patents) were recently put into service at this works.

This type of furnace enables high grade steel to be made under ideal metallurgical conditions—low operating costs, perfect cleanliness and freedom from carbon pick-up.

A product of absolute uniformity is thus assured.

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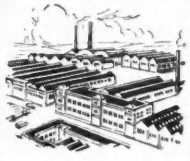

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BRIGHTON
BRISTOL
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HULL
INVERNESS
IPSWICH
LEEDS
LEICESTER
LIVERPOOL
MANCHESTER
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Bureau of Standards
NOV 27 1936

G.E.C. Journal

IN THIS ISSUE.

THE ELECTRICAL CONTROL OF THE SWING SPAN OF KINCARDINE-ON-FORTH BRIDGE.

PHOTOELECTRIC CELLS.

THE DIESEL-ELECTRIC TUG "SIR MONTAGU."

THE APPRAISEMENT OF LOUD SPEAKERS—PART I.

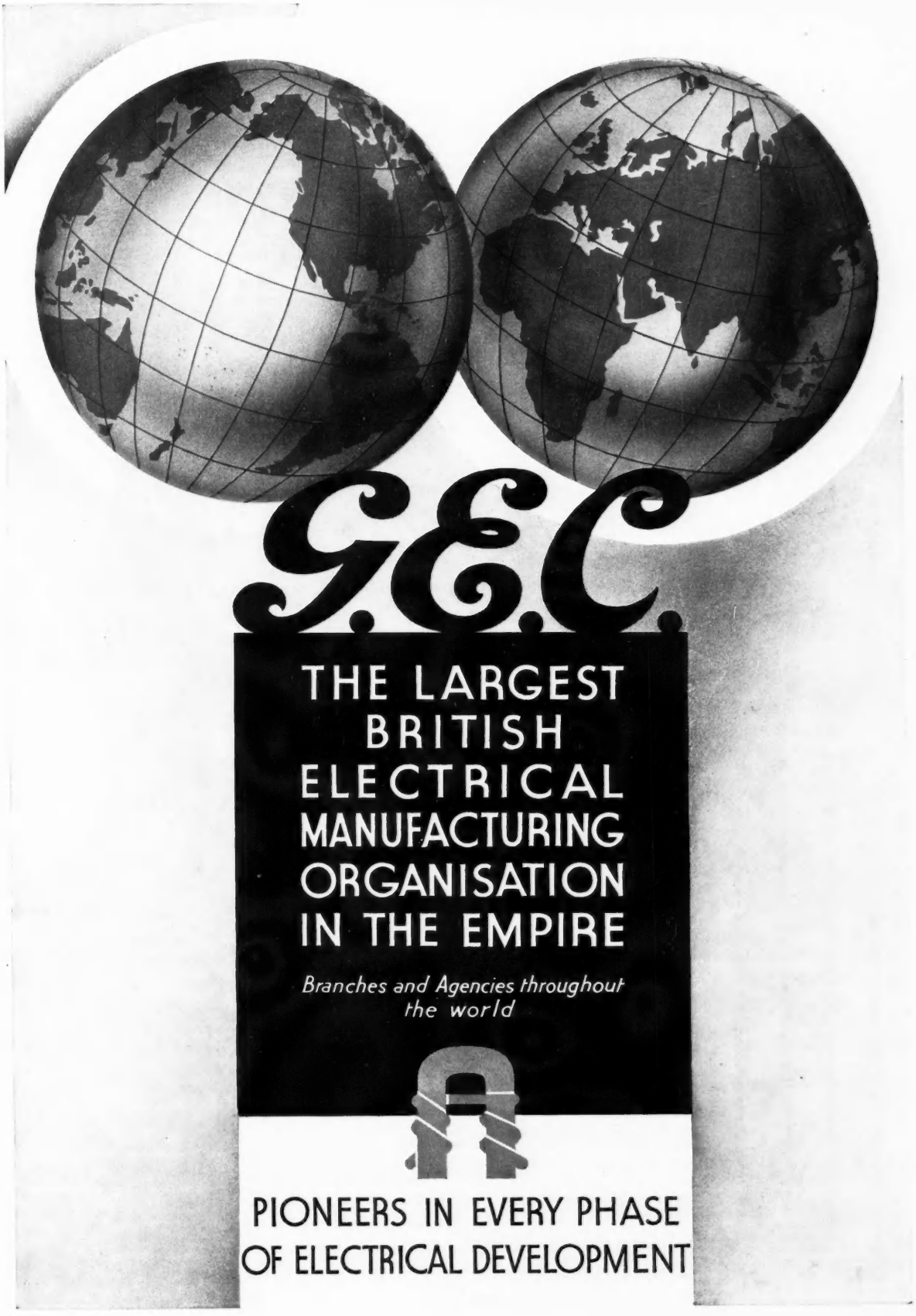
ELECTRIFICATION OF THE LUN CHONG COTTON MILL.

AUTOMATIC CONTROL OF ROAD TRAFFIC—PART II.

SOME TECHNICAL ASPECTS OF ARCHITECTURAL LIGHTING.

Vol. VII., No. 4. *November, 1936.*

THE GENERAL ELECTRIC CO. LTD
ENGLAND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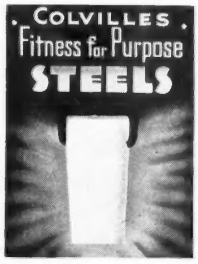

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Seventy years experience . . . in the problem of making holes in metals—of developing, accomplishing, perfecting.

Seventy years of close contact whilst progress marched, cutting steels improved and production soared to its present lofty peak.

Such is the foundation upon which are based the principles of design of the "S.D." Radial Drilling Machine here illustrated.

Range of sizes: 2ft. 7in. to 4ft. max. radius.

Nine spindle speeds. Hand or power feed. Rapid reverse for tapping. Plain or swivelling table with hand elevating motion. Belt or motor drive, and a Facility of Control hitherto unachieved.

An alternative design has round column and elevating swing-aside table.

Full details on request.

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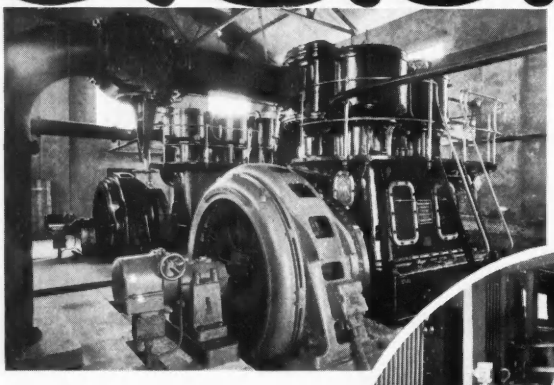
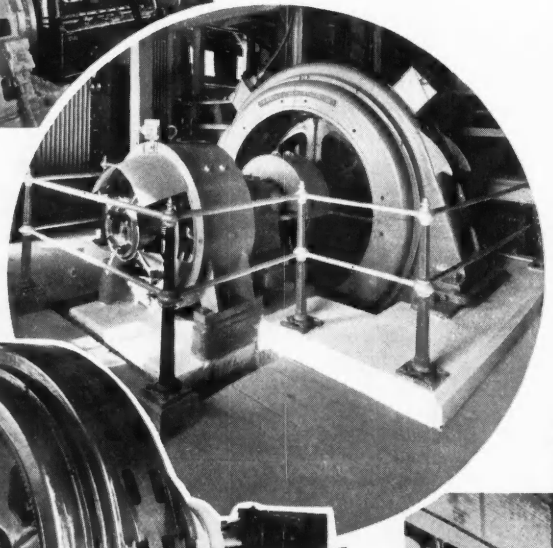
G.E.C. MOTORS

IN THE SOUTH AFRICAN MINING INDUSTRY

MADE IN ENGLAND



Two 750 h.p. 2100 volt slip ring motors, 245 r. p. m., driving air compressors for the Nigel G. M. Co., Ltd.

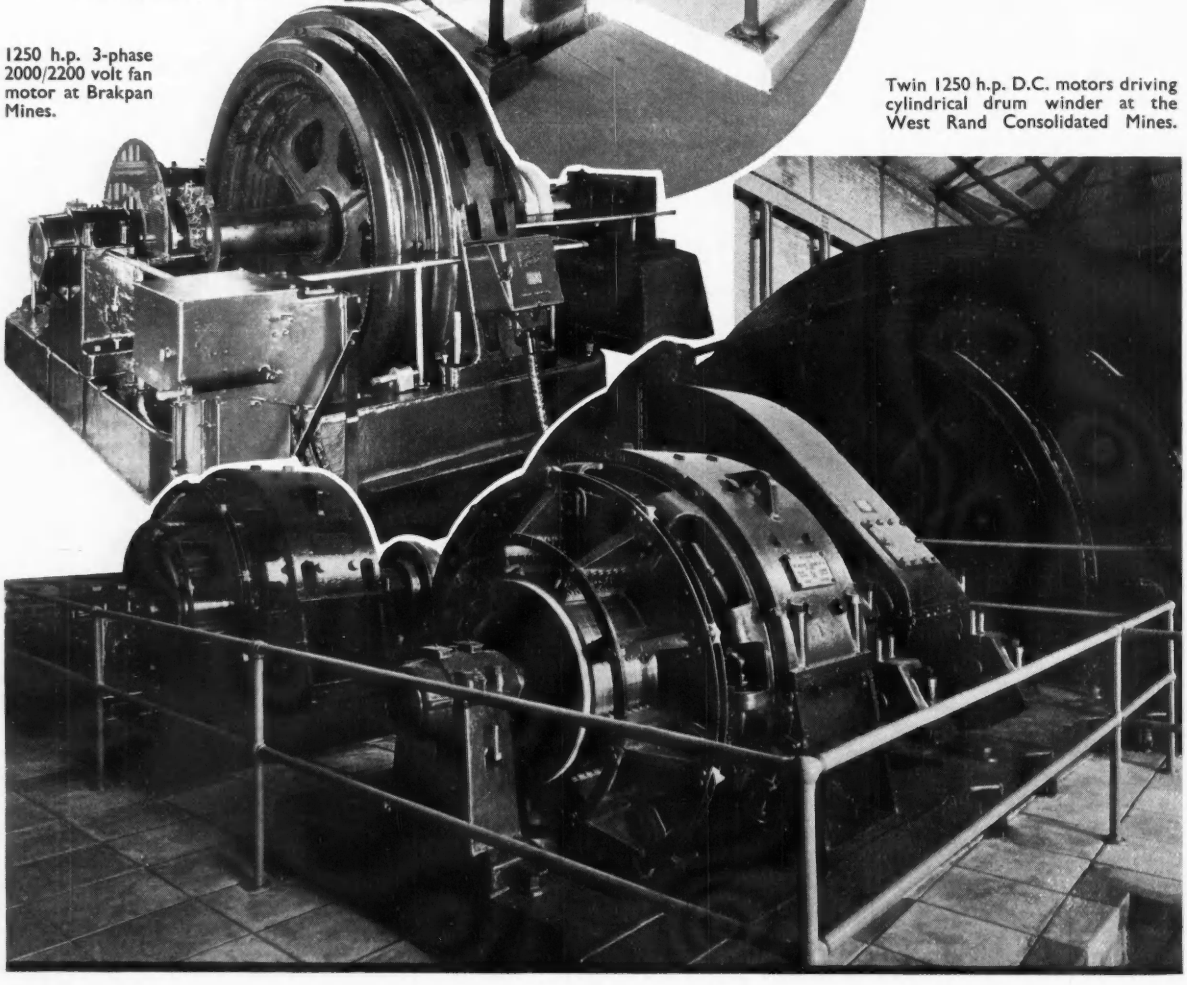


500 h.p. 3300 volt synchronous induction motor, 107 r.p.m., driving stamp mills for East Rand Proprietory Mines.

These views represent some typical applications of G.E.C. motors in the South African mining industry, where the motors have necessarily to be capable of giving satisfactory service under very arduous working conditions

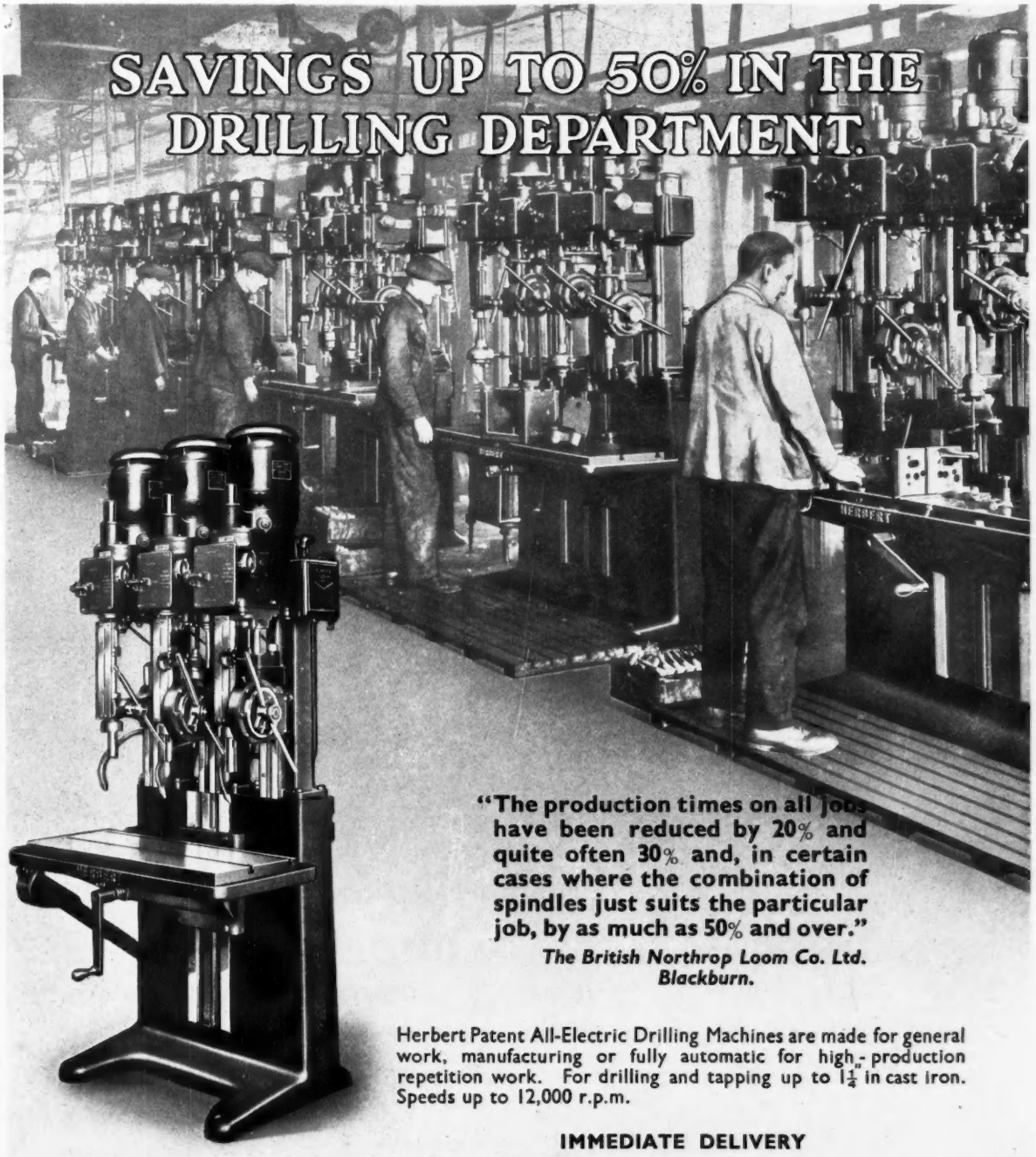
1250 h.p. 3-phase 2000/2200 volt fan motor at Brakpan Mines.

Twin 1250 h.p. D.C. motors driving cylindrical drum winder at the West Rand Consolidated Mines.



HERBERT

SAVINGS UP TO 50% IN THE DRILLING DEPARTMENT.



"The production times on all jobs have been reduced by 20% and quite often 30% and, in certain cases where the combination of spindles just suits the particular job, by as much as 50% and over."

The British Northrop Loom Co. Ltd. Blackburn.

Herbert Patent All-Electric Drilling Machines are made for general work, manufacturing or fully automatic for high-production repetition work. For drilling and tapping up to 1¼" in cast iron. Speeds up to 12,000 r.p.m.

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G.E.C. LIGHTING

at

PORTOBELLO BATHING POOL

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The lighting scheme for this new open air bathing pool which is one of the largest in the world, comprises :—

UNDER WATER FLOODLIGHTING

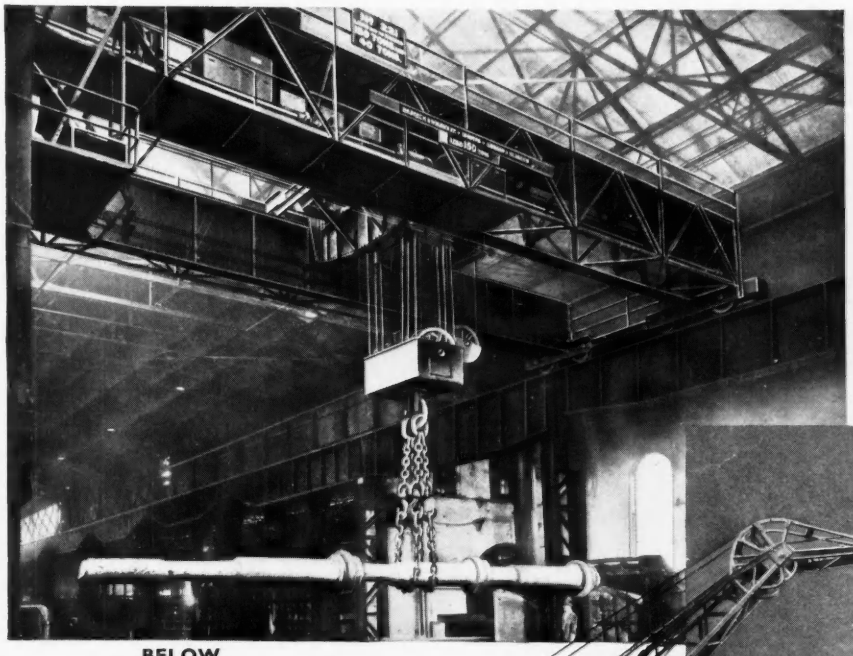
MAIN OVERHEAD LIGHTING

PROMENADE LIGHTING

GRAND STAND LIGHTING

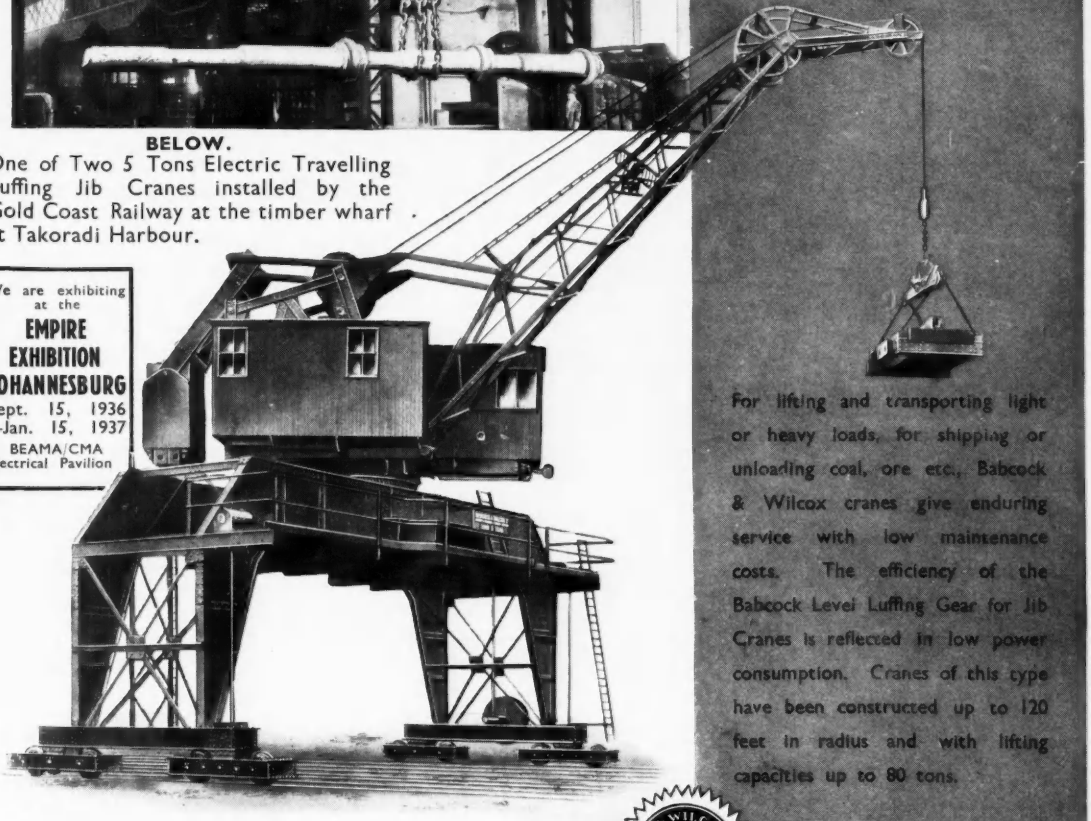
OSRAM LAMPS ARE USED THROUGHOUT

BABCOCK CRANES



LEFT.
150 Tons Electric Overhead Travelling Crane with 40 tons Auxiliary hoist at the Vickers Works of the English Steel Corporation Limited Sheffield.

BELOW.
One of Two 5 Tons Electric Travelling Luffing Jib Cranes installed by the Gold Coast Railway at the timber wharf at Takoradi Harbour.



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BEAMA/CMA
Electrical Pavilion

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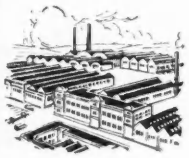

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